NASA Contractor Report 177414

Large Deployable Reflector (LDR) System Concept and Technology Definition Study Analysis of Space Station Requirements for LDR

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(NASA-CR-177414) LARGE DEPLOYABLE REFLECTOR (LDR) SYSTEM CONCEPT AND TECHNOLOGY DEFINITION STUDY. ANALYSIS OF SPACE STATION REQUIREMENTS FOR LDR Final Technical Report (Eastman Kodak Co.) 115 p

N93-12592

Unclas

G3/89 0130689

CONTRACT NAS2-11861
April 1989

NASA

National Aeronautics and
Space Administration

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Ames Research Center
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1.0 EXECUTIVE SUMMARY

Large Deployable Reflector (LDR) is conceived as a future space-based, 20-meter aperture astronomical facility for performing astrophysical observations in the infrared through submillimeter wavelength region. Because of its massive size, LDR would be assembled in space at low earth orbit altitude, before being deployed to its final, higher operational orbit. During its lifetime, LDR could be serviced and possibly refurbished in space.

This study report addresses the potential role of the permanently manned Space Station in enabling the LDR concept, and the requirements that must be met by the Station to benefit LDR.

Technology development, assembly, checkout, deployment, and refurbishment of LDR can be significantly enhanced by the capabilities of the Space Station.

1.1 STUDY BACKGROUND AND OBJECTIVES

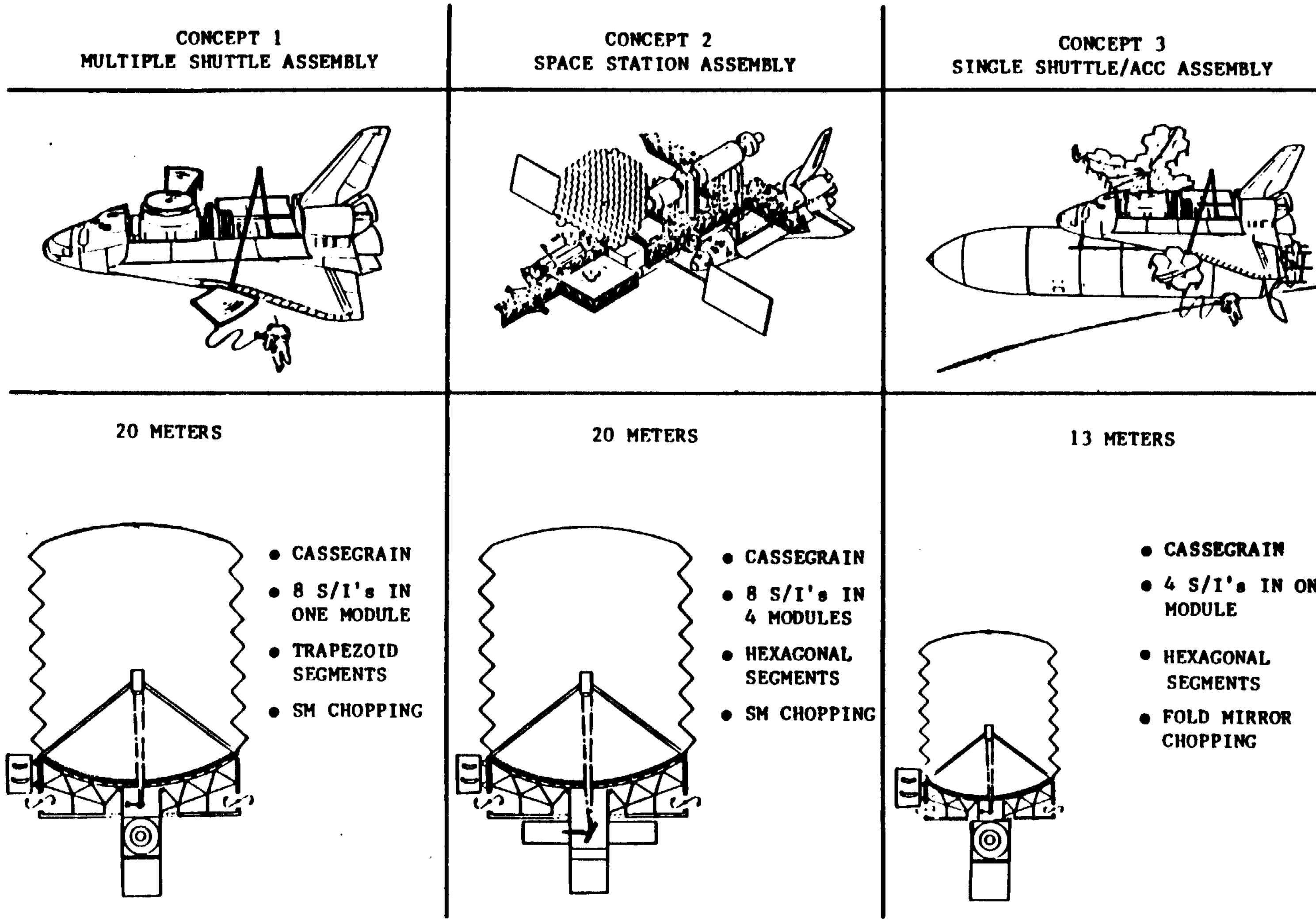
A "pre-phase A" study of LDR system concepts and technology needs was conducted in 1984-85 for NASA Ames Research Center by a team consisting of Kodak, McDonnell Douglas Astronautics Company - Huntington Beach, and Fairchild Space Company. Findings were presented at the NASA-sponsored LDR Technology Workshop held 17-22 March 1985 at the Asilomar Conference Center. Preliminary results were simultaneously published in a two-volume draft report dated 15 March 1985 distributed at the Workshop. The final report entitled "LDR System Concept and Technology Study - Final Technical Report", also in two volumes, was published in March 1986.

The Kodak study team evolved three alternative system concepts for guiding the technology definition and development required by LDR (Figures 1.1-1 and 1.1-2). Two concepts were for 20-meter diameter Cassegrain optical forms. The first (Concept 1) featured assembly in space by means of a series of Shuttle flights. The second (Concept 2) was established for assembly of LDR on the Space Station. Concept 3 was aimed at satisfying a single Shuttle launch approach, resulting in a reduced aperture (13 meters) and lesser performance concept. Thirteen subsystem analyses were performed and are reported in Volume I of the Final Technical Report.

Technology advances required for LDR were identified and ranked, (Figure 1.1-3) and a Technology Development Plan completed and priced. A summary schedule for recommended technology development efforts to meet an FY93 LDR start is shown in Figure 1.1-4. Details are contained in Volume II of the Final Technical Report.

Subsequent to the LDR Technology Workshop, Modification 5 was added to the study contract to incorporate an analysis of Space Station requirements for LDR, the subject of this document. Figure 1.1-5 highlights these additional study tasks, which were carried out by Kodak and McDonnell Douglas in the second half of 1985.

The Benefits Analysis task considered how LDR might benefit from use of the Space Station during LDR assembly, check-out, deployment, servicing and reconfiguration/refurbishment. Novel concepts were examined and advantages and disadvantages of the various options explored resulting in the selection of a single scenario and a preliminary update of the LDR Space Station data base, mission SAA 0020.



HIGHLIGHTS OF SYSTEM CONCEPTS DEVELOPED IN PRIOR STUDY

Figure 1.1-1

	CONCEPT 1 MULTIPLE SHUTTLE ASSEMBLY 20M APERTURE	CONCEPT 2 SPACE STATION ASSEMBLY 20M APERTURE	CONCEPT 3 SINGLE SHUTTLE/ACC ASSEMBLY 13M APERTURE
PERFORMANCE • CONFORMANCE TO STUDY BASELINE REQUIREMENTS FOR LDR OBSERVATORY	POTENTIAL TO MEET ALL REQUIREMENTS	POTENTIAL TO MEET ALL REQUIREMENTS	• DOES NOT MEET APERTURE REQUIREMENT • LESS RESOLUTION • LONGER OBSERVATION TIME • 4 INSTRUMENTS
• TRANSPORTATION TO ORBIT, ASSEMBLY/ DEPLOYMENT	• CONSTRAINED BY SHUTTLE LOITER TIME LIMITS • MAJOR SHUTTLE SCHEDULING IMPACT • LONG INITIAL ASSY PERIOD • SPACECRAFT IS "PLATFORM"	• MANNED SPACE STATION MUST BE AVAILABLE • MORE FLEXIBLE ASSY SEQUENCE, SHUTTLE MANIFEST	• REQUIRES ACC DEVELOPMENT • ACC CONTAMINATION CONCERNS, RMS • DIFFICULT AUTOMATION
• IN-ORBIT SERVICING, REPAIR, UPGRADE, REFURBISHMENT	CONSTRAINED BY SHUTTLE LOITER TIME	• ENHANCED OPPORTUNITY FLEXIBILITY	CONSTRAINED BY SHUTTLE LOITER TIME
SCHEDULE • POTENTIAL FOR ACHIEVING NEEDED LEVEL OF TECHNOLOGY READINESS BY 1991 (FOR LDR)	GOOD	GOOD	BETTER (BASED ON DESCALING ALONE, BUT DEPLOYMENT AUTOMATION MAY OFFSET ADVANTAGES)
COST • TOTAL COSTS TO LDR IOC	HIGHEST (DEDICATED SHUTTLES)	HIGH	LOWEST (IF ADDITIONAL AUTOMATED DEPLOYMENT DESIGN FEATURES ATTAINABLE)

SYSTEM CONCEPTS COMPARISON SUMMARY

Figure 1.1-2

HIGH - 5

OAST CATEGORY	TECHNOLOGY
B	DYNAMIC STRUCTURAL CONTROL
D	HUMAN FACTORS
E	HYBRID CRYOGENIC SYSTEM FOR SCIENCE INSTRUMENTS
G	ACTIVE PRIMARY MIRROR
G	PRIMARY MIRROR CONTAMINATION PROTECTION

MEDIUM - 17

OAST CATEGORY	TECHNOLOGY
A	PRIMARY MIRROR SEGMENT SENSING AND CONTROL APPROACH
A	FOLD MIRROR CHOPPING
A	SECONDARY MIRROR CHOPPING
A	FINE GUIDANCE SENSING AND CONTROL
B	DYNAMIC DIMENSIONAL STABILITY
B	DYNAMIC RESPONSE PREDICTION PRECISION
B	STRUCTURAL NONLINEARITY
B	LOW JITTER AND RAPID SETTLING
B	VERIFICATION/ACCEPTANCE GROUND TESTING
B	MECHANICAL STABILITY - DAMAGE TOLERANCE
B	STEP SUNSHIELD
B	SECONDARY MIRROR TEMPERATURE CONTROL
B	PRIMARY MIRROR TEMPERATURE CONTROL
E	CRYOGENIC SYSTEMS FOR DETECTOR TEMPERATURES LESS THAN 0.3°K
E	ROBOTIC ON-ORBIT CRYOGENIC REPLENISHMENT
G	GLASS MATERIAL FOR THE PRIMARY MIRROR
G	COMPOSITE MATERIAL FOR THE PRIMARY MIRROR

LOW - 4

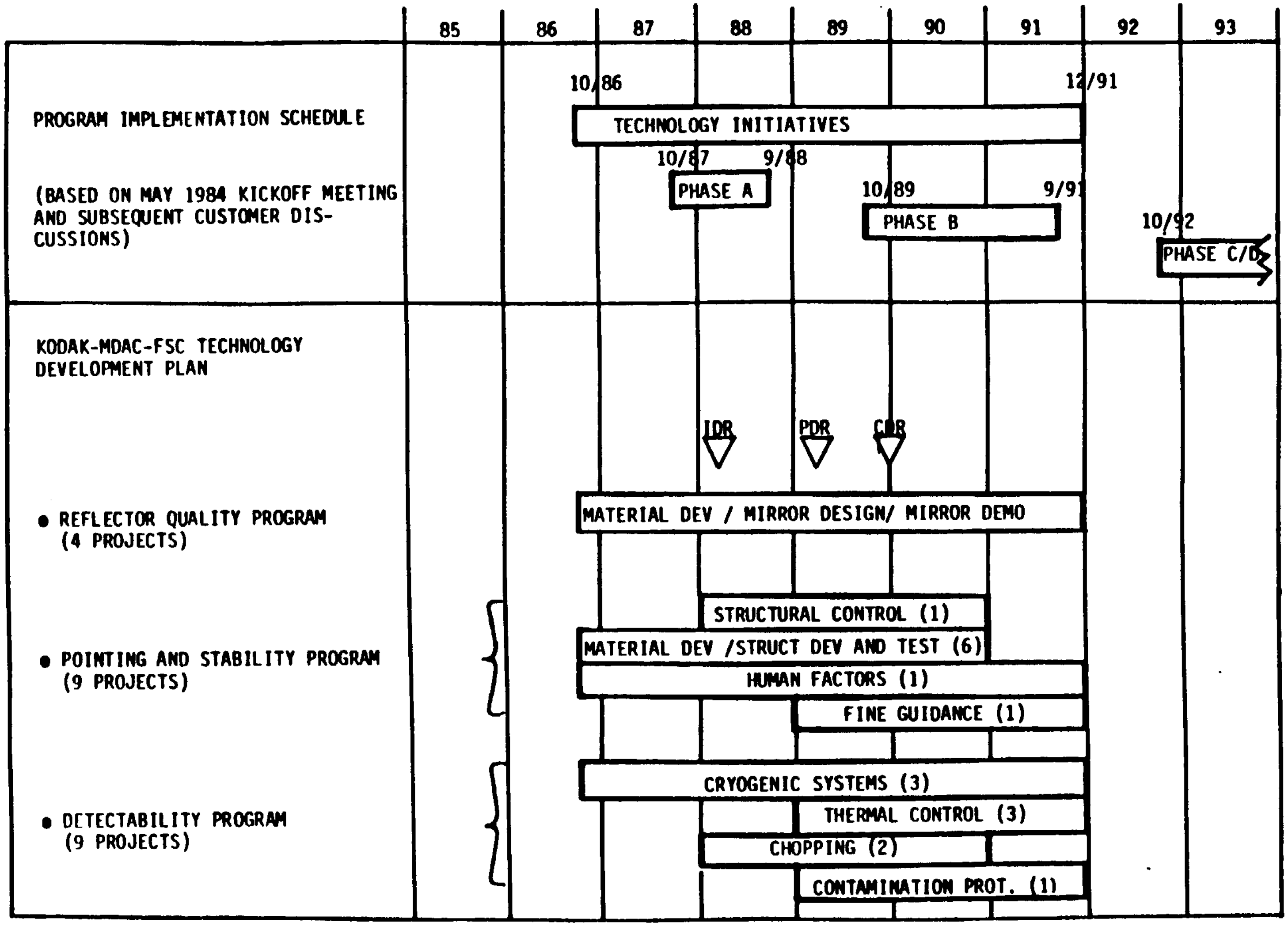
OAST CATEGORY	TECHNOLOGY
A	SECONDARY MIRROR SENSING AND CONTROL APPROACH
B	COLLAPSIBLE SUNSHIELD
B	SPACECRAFT BUILDUP ON ORBIT
G	OFF-AXIS MIRROR SEGMENT PROCESSING

NOT RATED - 5

A	NOISE REDUCTION IN CONTROL MOMENT GYROS
C	STRUCTURAL DYNAMICS: ADVANCED POWER SYSTEM
C	MONOPROPELLANT REFUELING
H	ACC CONTAMINATION PROTECTION/REMOTE MANEUVERING ARM
H	SHUTTLE BAY CONTAMINATION PROTECTION

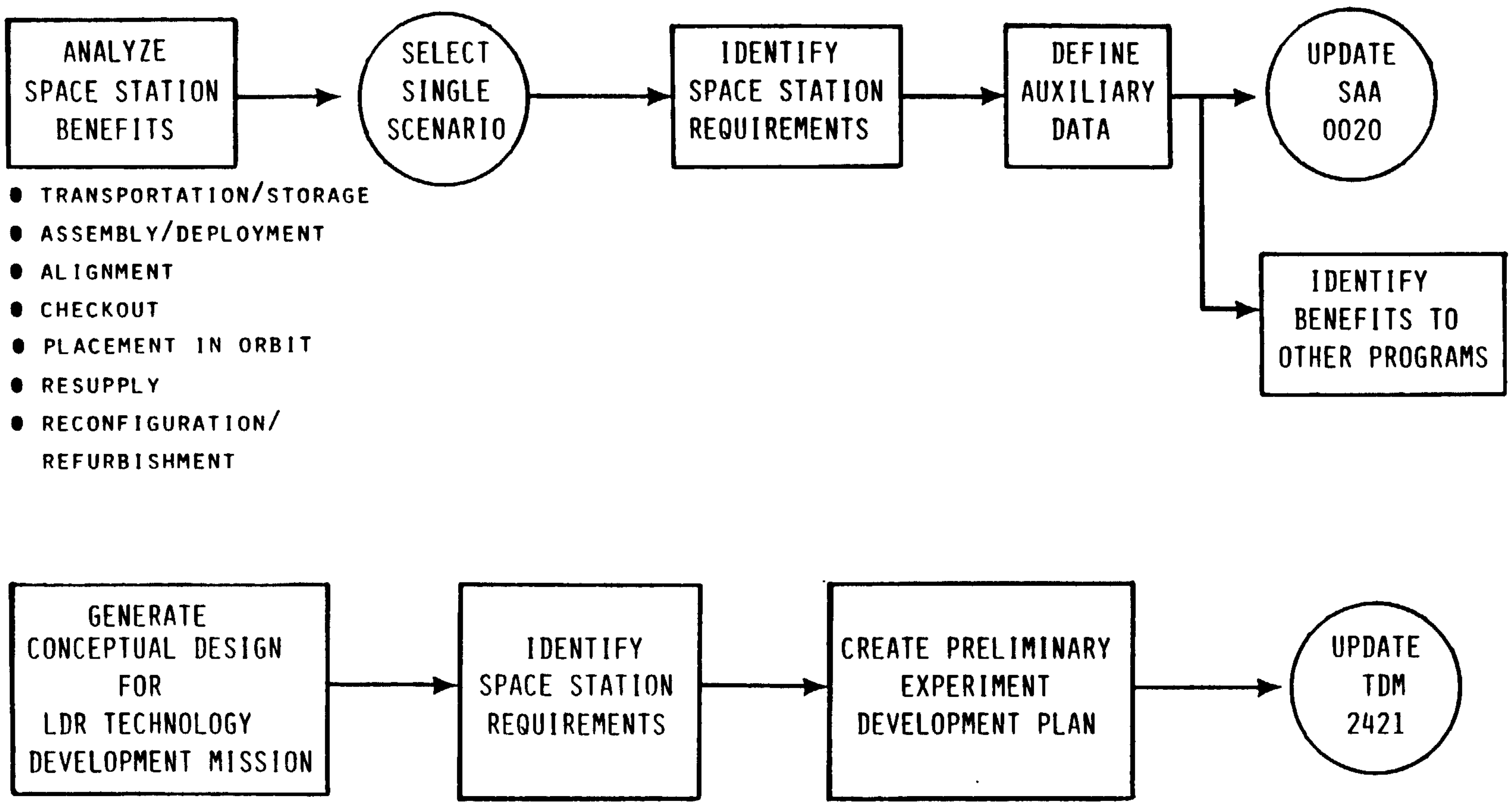
PRIORITIZED TECHNOLOGY AUGMENTATION PROGRAMS

Figure 1.1-3



SUMMARY LDR TECHNOLOGY DEVELOPMENT SCHEDULE

Figure 1.1-4



STUDY ACTIVITIES AND FLOW

Figure 1.1-5

In the next tasks, the aim was to define the resulting requirements on the Space Station such as space, placement, EVA/IVA, storage, etc., and specify relevant quantitative and qualitative data including number of flights, power, data rates, and special equipment. A final update of SAA 0020 and a definition of those LDR capabilities that could be used by other missions rounded out the study of the LDR primary mission.

A second path of investigation required by Modification 5 was a study of how Space Station capabilities could be used for an LDR/active optics development and demonstration mission. Initially, a preliminary mission design and preliminary update of technology development mission TDM-2421 were required. These were followed by development of a conceptual design, to define the experiment and its resource requirements on the Station, development of representative resource timelines and development of an experiment development plan. A final update of the TDM was required at completion.

The study followed the stated plan. The results are documented in this report and were presented at NASA Ames Research Center and Johnson Space Center on 18 and 20 November, 1985.

1.2 LDR BASELINE FOR SPACE STATION STUDY

The scientific requirements for LDR, which served as the basis for this study, are shown in Figure 1.2-1. The observatory concept selected as the baseline for this Space Station requirements study is shown in Figure 1.2-2. This LDR representative concept incorporates features from the three earlier study concepts cited above and is not optimized.

The integral Spacecraft provides attitude control, power, communication, command and data handling and propulsion. Four to eight scientific instruments (SI's) are mounted radially about the centerline of the primary mirror. A "strawman" complement of instruments published by the LDR Science Coordination Group is reproduced in Figure 1.2-3. The SI's are cooled by a hybrid cryogenic cooling unit mounted between the SI's and the spacecraft. A rotatable 45° mirror is capable, upon command, of directing the focused energy into any one of the scientific instruments. A system of support rods and joints are assembled in space to form the primary mirror support truss. This truss also supports the secondary mirror assembly and the fine guidance sensor. The secondary mirror assembly incorporates the secondary mirror, chopping drive mechanism, mirror positioning servos and active cryogenic cooling mechanisms. The primary mirror consists of a central "rock-of Gibralter" and 60 hexagonal segments with associated adjusting servos and hexagonal support frames. Thermal control of the telescope is provided by a combination of active and passive control. The back of the primary mirror is maintained by heaters at 198°K while the thermal step shield/sunshield reduces solar and earth albedo inputs on its face. An aperture cover at the viewing end of the stepshield can be closed, for contamination control during assembly, deployment to operating orbit, and servicing. It remains open during normal operation.

1.3 STUDY RESULTS: MAJOR SPACE STATION REQUIREMENTS FOR LDR

Three features of LDR dominate the impact that LDR has on Space Station requirements: The large size and mass of LDR; the need for extremely low levels of contamination, and the need to cryogenically cool the Scientific Instruments. None of these need cause "scarring" of the station.

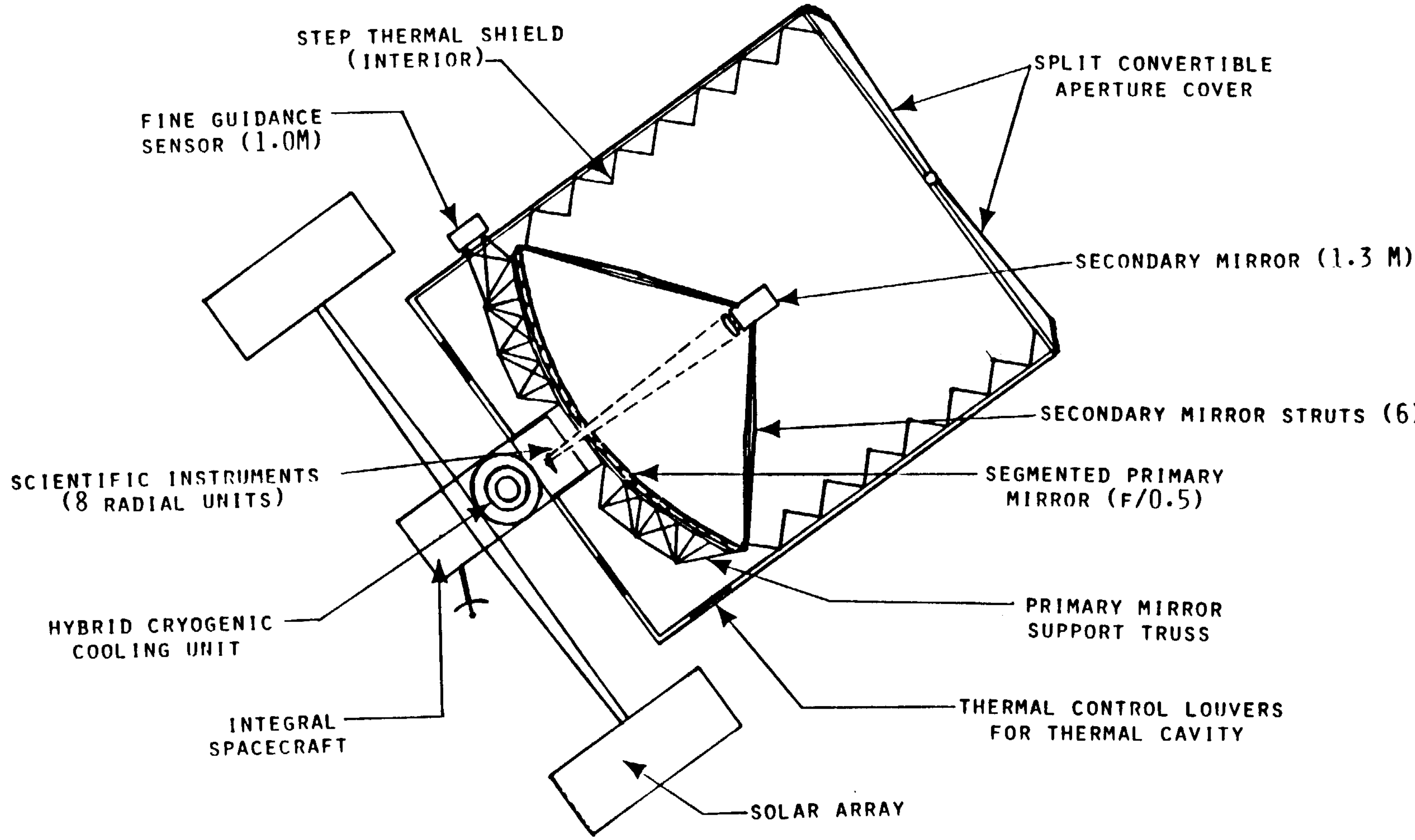
Parameters	Requirements
Diameter	20 m primary, 1 m secondary
Field of view	$\geq$ 3 arcmin
F/Ratio[b]	System F/10, primary F/0.5
Shortest wavelength of diffraction-limited performance	30-50 μm (aperture efficiency > 30% at 30 μm)
Light bucket blur circle[a]	2.0 arcsec (at 1-4 μm)
Optics temperature	Primary $\leq$ 200K (±1 K uniformity), secondary $\lesssim$ 125 K (±1 K uniformity)
Emissivity (system)	0.05
Absolute pointing	0.05 arcsec
Jitter	0.02 arcsec - within 1 min after slew
Slew	20 - 50°/min
Scan	1° x 1° - linear scan at 1°/min
Track	0.2°/hr (for comets $\gtrsim$ 25° from Sun)
Chopping[b]	Yes, 2 Hz, 1 arcmin (reactionless)
Sidelobes	Low near sidelobes
Other	Limited cross polarization
Sky exclusion	60°-90° from Sun, $\gtrsim$ 45° from Earth
Cryo system	Various temperatures in the range 0.1 K to 50K, 1.5 kW total power required
Lifetime	> 10 yr, approximately 3 yr revisit

[a] The tolerances (e.g., rms surface accuracy) needed to achieve a value of 2 arcsec for the light bucket mode are more severe than the tolerances associated with a diffraction limit of 50 μm. This requirement will be studied further.

[b] Approximate.

CONTRACT LDR SYSTEM PARAMETERS AND PERFORMANCE REQUIREMENTS

Figure 1.2-1



STUDY LDR CONCEPT CONFIGURATION

(20-METER APERTURE CASSEGRAIN)

Figure 1.2-2

Number	Instrument	Type	Wavelengths
1	High resolution spectrometer	SIS multichannel heterodyne receiver	3 mm - 400 μm
2	High resolution spectrometer	Schottky diode multichannel heterodyne receiver	500 - 200 μm
3	High resolution spectrometer	Photoconductor multichannel heterodyne receiver	200 - 35 μm
4	Medium resolution spectrometer	Fabry-Perot interferometers with imaging detector arrays	200 - 35 μm
5	Medium-to-low resolution spectrometer	Multichannel grating spectrometers	200 - 35 μm
6	Heterodyne array	SIS array	?
7	Far-infrared camera	Photoconductor arrays, broadband filters, interference filters	200 - 30 μm (5 - 1 μm)
8	Submillimeter camera	Bolometer arrays, broadband filters, interference filters FTS?	1 mm - 100 μm

LDR STRAWMAN INSTRUMENT COMPLEMENT
Figure 1.2-3

The first area of major impact on the Space Station is caused by LDR's unique combination of large size and substantial mass. The total mass of LDR, exclusive of assembly and test equipment, will be about 52,000 kg and, when fully assembled, it will occupy a volume of approximately 38,500 cubic meters. By the time LDR is launched, in the late 1990's, a number of large aperture structures will have already been assembled on the Station but none combining the projected large size and mass of LDR.

For reasons of both size and mass, the optimum position for mounting and assembly of LDR on the Space Station will be near the Station's own center of mass. For the "Power Tower" Space Station configuration, which this study used as a baseline, this position will be in the area designated as the Large Mission Assembly and Test Site on the trailing side of the mid-keel, with storage of major components nearby in the mid-keel area. This position will also facilitate movement of material from the Shuttle docking site to either storage or assembly site with the assistance of the Mobile Remote Manipulator System (MRMS). (An early look at the new "Dual Keel" Station configuration indicates LDR might best be accommodated on the aft side of the left keel.)

It may take as many as five STS flights, over a 9 to 12 month period, to bring the entire LDR Observatory to the Space Station. Assembly is expected to take about 250 hours of IVA and 400 hours of EVA over about 100 operational days. Checkout, on the Station, will take another 144 hours of EVA and 108 hours of IVA. Final alignment and checkout, with LDR orbiting in close proximity to the Space Station, will take about 50 hours of IVA. These estimates assume maximum use will be made of teleoperation and robotics techniques and automatic test equipment.

The Space Station may also be impacted by extreme sensitivity to contamination of LDR optical surfaces. However, the LDR construction concept attempts to lessen this sensitivity in a number of ways. Critical LDR components carried into orbit will, as necessary, be stored in sealed containers. At an early stage of assembly, the LDR sunshade and lens cover will be combined with a Space Station mounted skirt to form an environmental shroud to seal out contaminants. Further, the surfaces of the primary and secondary mirrors will be covered with "strippable" coatings to protect them from contamination. Still, care must be taken to avoid significant contamination from Shuttle docking as well as Station based sources, including astronaut maneuvering aids. And, the additional protective devices suggested in this concept will require additional manipulation, storage and astronaut training.

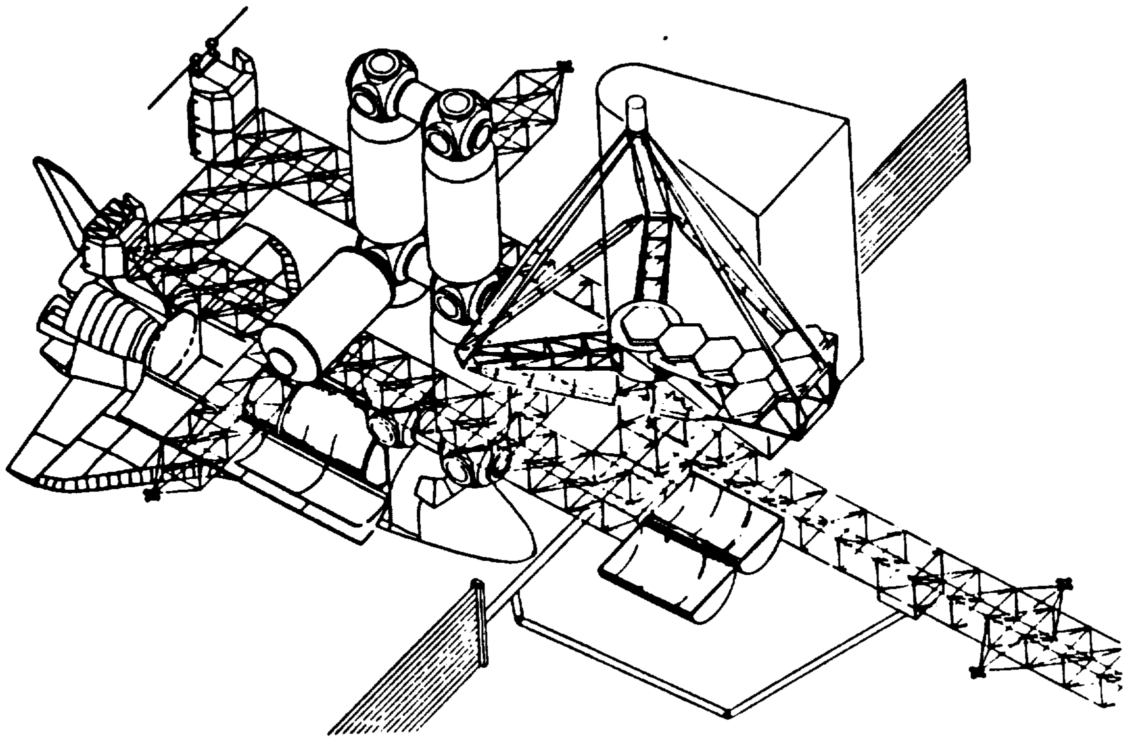
The third major impact on the Space Station concerns the very low temperatures the Scientific Instruments must be maintained at and the storage and handling of the required cryogenic fluids. To reduce the need for additional cryogenic fluid and/or lengthy cooldown periods the instruments, which should be launched last, will be launched in the cooled condition and maintained cooled while on the Space Station. This will require the continuous availability of approximately 2,900 watts, of the 4,100 watt peak power requirement, to drive the active hybrid cryogenic cooling system. Also, the coolants, consisting of liquid Nitrogen, liquid Hydrogen, liquid Helium and superfluid Helium, may need to be "topped-up" before final deployment of LDR from the Station. They will also need to be replaced on the Space Station when LDR returns for servicing. Total coolant mass is expected to be about 7,500 kg. While LDR is not expected to be the first payload requiring replacement of cryogens on the Station, the volume and variety of coolants may represent a growth in capability.

Other observatory requirements on the Space Station are the need for an assembly yoke, 160 KBPS maximum data rate, 4,100 watts maximum power, 3 racks of test equipment in the LAB module, re-supply (by OMV) every 3 years and reconfiguration/refurbishment (including instrument changeout) on the Space Station every 6 years.

1.4 TECHNOLOGY DEVELOPMENT MISSION

A Technology Development Mission could serve as a precursor to LDR to test critical technology issues. A concept for such a Technology Development Mission (TDM-2421) was developed as part of this study. It is described in detail in Section 6.0 of this report.

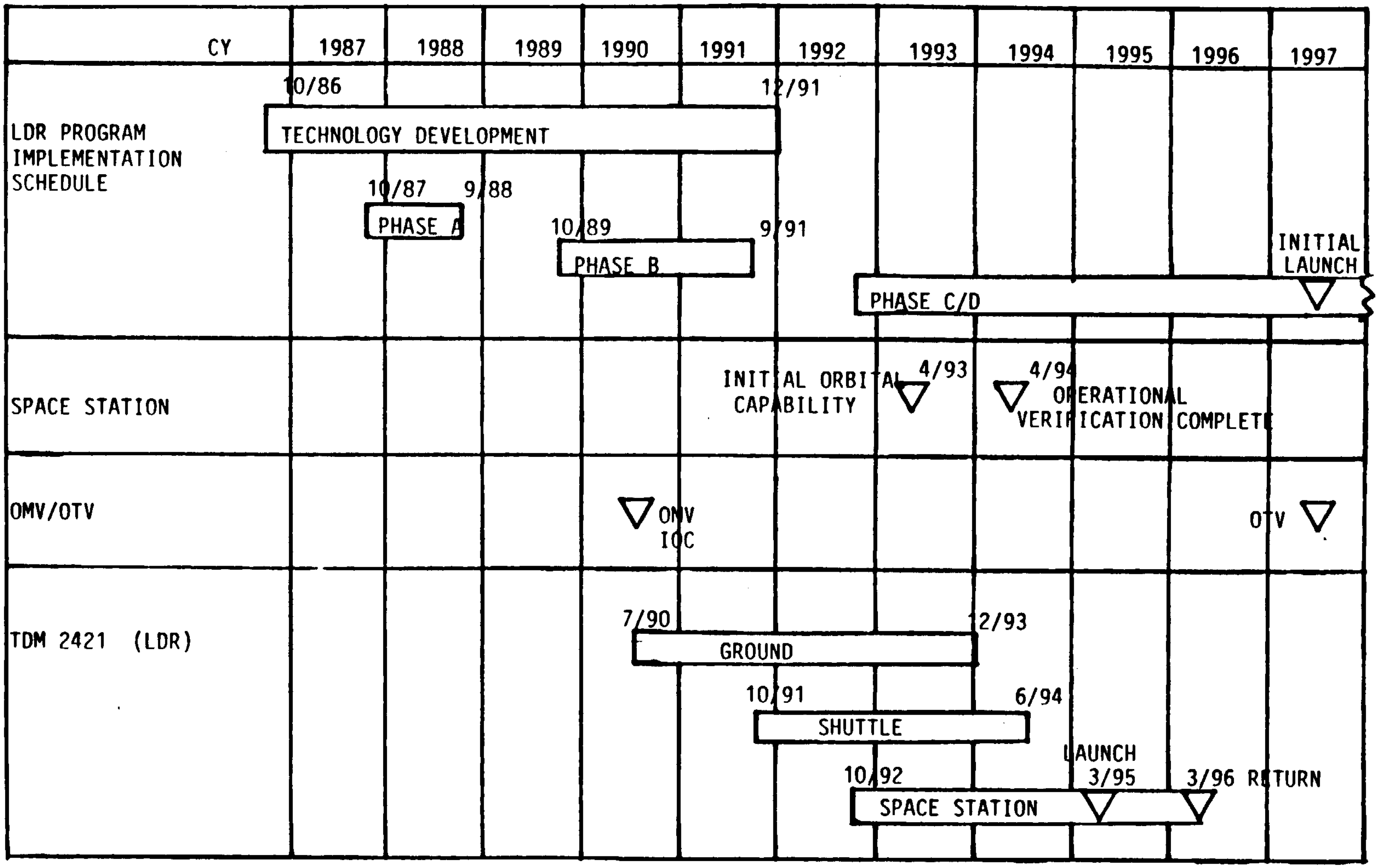
Preserving the large scale nature of the mirror segments and support structure is critical to the success of testing many of the most important technology issues. Further, it seems possible to test these components without burdening the test with the development of costly focal plane scientific instruments. Therefore, rather than a small scale telescope, a partial LDR having a full-scale secondary mirror, with support structure, instruments, and a full sized radial section of the primary mirror is proposed. The assembly will be heavily instrumented but will not include astronomical sensors in the focal plane. An overall view of the proposed TDM configuration is shown in Figure 1.4-1.



LDR TECHNOLOGY DEVELOPMENT MISSION ON SPACE STATION
Figure 1.4-1

The proposed experiment would provide a technology base for the transportation, construction, alignment, test and operation of large aperture segmented mirrors having high surface accuracy optical figures.

Figure 1.4-2 shows an overall TDM-2421 planning schedule.



TECHNOLOGY DEVELOPMENT MISSION 2421
PLANNING CONSIDERATIONS
Figure 1.4-2

2.0 BENEFITS OF USING SPACE STATION

2.1 ADVANTAGES OF SPACE STATION

Major factors affecting LDR assembly are shown in Figure 2.1-1. The huge size of LDR, weighing more than 50,000 KG, with a volume greater than 38,500 M^2, indicates a need for several STS flights to place the total system in orbit. Availability of a Space Station will provide the necessary support services to allow off-loading and storage of material from individual STS flights and assembly and check-out unconstrained by limits of STS stay time. Further, attachment of LDR to the Space Station will obviate the early need for a stable spacecraft to serve as a "base" for LDR assembly. This will conserve spacecraft expendables and expand the number of assembly options available.

Contamination of LDR optical surfaces is a major concern. Assembly on the Space Station will help to isolate it from contamination from the Shuttle. Although the Space Station may also be a source of contaminants, the assembly flexibility provided by the availability of storage, extra handling equipment, stable mounts and nearly continuous availability of EVA and IVA will make it easier to take preventative measures, including the early construction of appropriate contamination shrouds.

• HUGE SIZE OF LDR (THERMAL SHIELD, APERTURE)	⇒	NUMBER OF SHUTTLE LAUNCHES, SPECIAL ATTACHMENT, EVA TIME
• CONTAMINATION PROTECTION	⇒	SHIELDING, ASSEMBLY SEQUENCE, TIMELINES
• RE-ESTABLISHMENT OF ALIGNMENT OF OPTICAL SYSTEM IN ORBIT	⇒	DETACHED TESTING NEAR STATION
• "COOLDOWN" TO SYSTEM CRYOGENIC TEMPERATURE	⇒	MODULAR UNIT FOR S/I'S, COOLING SYSTEM, SPACECRAFT SHOULD BE LAUNCHED LAST (START COOLING BEFORE LIFTOFF)
• SAFETY		

MAJOR FACTORS AFFECTING LDR SPACE ASSEMBLY
ON SPACE STATION
Figure 2.1-1

The Space Station will also enhance the process of cooldown of Scientific Instruments (SI's) to operating temperature. Construction flexibilities will allow the Scientific Instruments to be launched last. They can be pre-cooled on the ground and easily maintained in the cooled state during launch, rendezvous, docking and assembly, and quickly placed in operating condition with minimum use of their limited supply of expendable cryogens. In the unlikely event that too much of the cryogen supply is used, it will be possible to "top-up" the tanks on the Space Station before placement of LDR in its operational orbit.

The last events in the presently envisioned scenario, prior to insertion into operational orbit, are re-establishment of optical alignment and verification of SI's in lower earth orbit. The Space Station can accommodate the specialized equipment needed to assist in this final stage of mission readiness verification by monitoring and controlling the process while the assembled LDR is flying in close proximity to the Space Station. If serious problems are encountered, the LDR can be returned to the Space Station where specialized tools and personnel will be available.

Further, the LDR must be re-supplied with expendable cryogens and propellants every three years. Since present plans are to base an OMV at the Space Station, this vehicle can be used to transfer cryogens (from lower earth orbit) to LDR. Teleoperator and robotics techniques, developed in conjuction with other missions, having similar re-supply needs, may be used to facilitate transfer at the LDR. When it becomes necessary to reconfigure and refurbish LDR, the station again becomes a logical choice. The station-based OMV or the LDR spacecraft can return LDR to the station where facilities and tools developed for initial assembly and deployment can be used to assist in reconfiguration/refurbishment, checkout and redeployment. The possibility of an extended stay at the station provides greater flexibility and reduces cost and risk.

2.2 ACCOMMODATION OPTIONS

2.2.1 Storage

Options for storage of LDR components include storage on the Space Station; tethered to Space Station; a separate co-orbiting "warehouse platform"; storage on Space Station with build-up nearby and storage on the Space Shuttle either attached to the station or loitering nearby.

A separate co-orbiting platform would be very costly, carry a high risk and require a great deal of new development. It might be shared with other missions but few have been identified that would benefit from such a costly and (because of the need for multiple docking and limited Shuttle stay time) risky arrangement. Tethering would offer no net advantage to LDR compared to storage on the station. It would reduce the demand on storage space at the station but at a substantial additional cost, risk and complication to Space Station operations. Build-up near the station, with storage on the station, would isolate the build-up process from Space Station contamination but subject it to contamination from the Shuttle. Further, it would remove the assembly process from all of the assembly and check-out aids available at the Space Station. Storage on the Shuttle might be possible for short periods of time but the extended periods of time required for LDR would be a costly and impractical diversion of Shuttle capability.

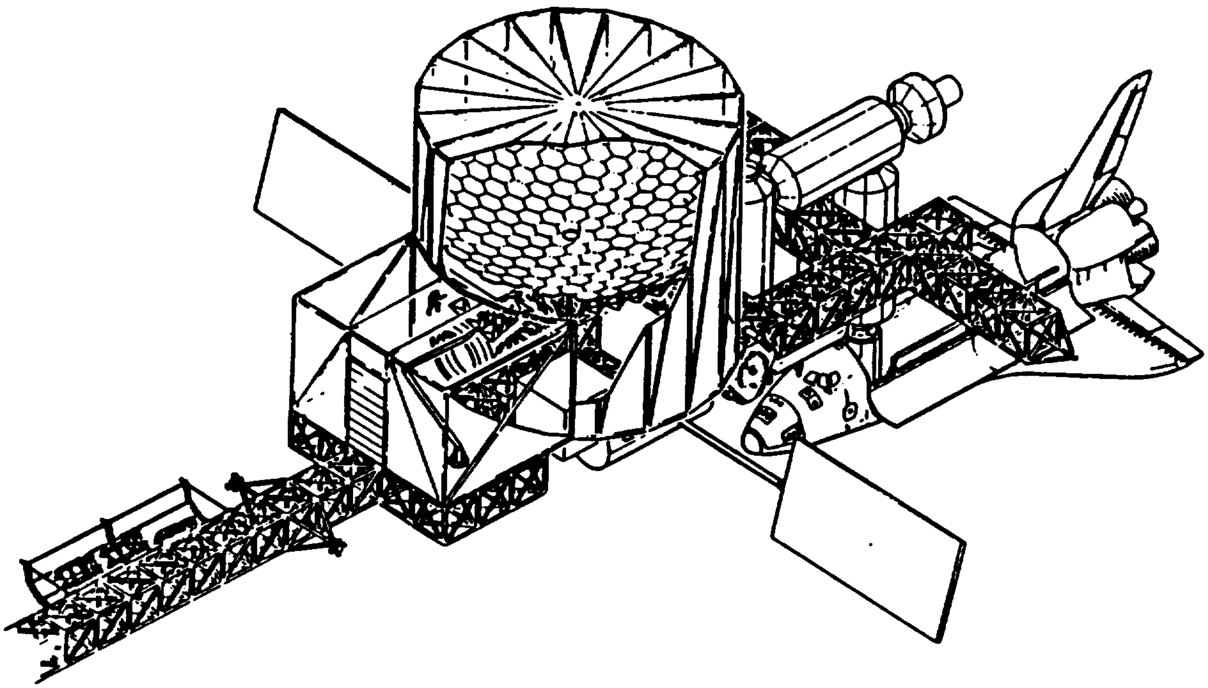
2.2.2 Assembly/Deployment

Three principal options appear to be available. The LDR could be assembled as a free flyer (tended from the station), tethered to the station, or attached to the station.

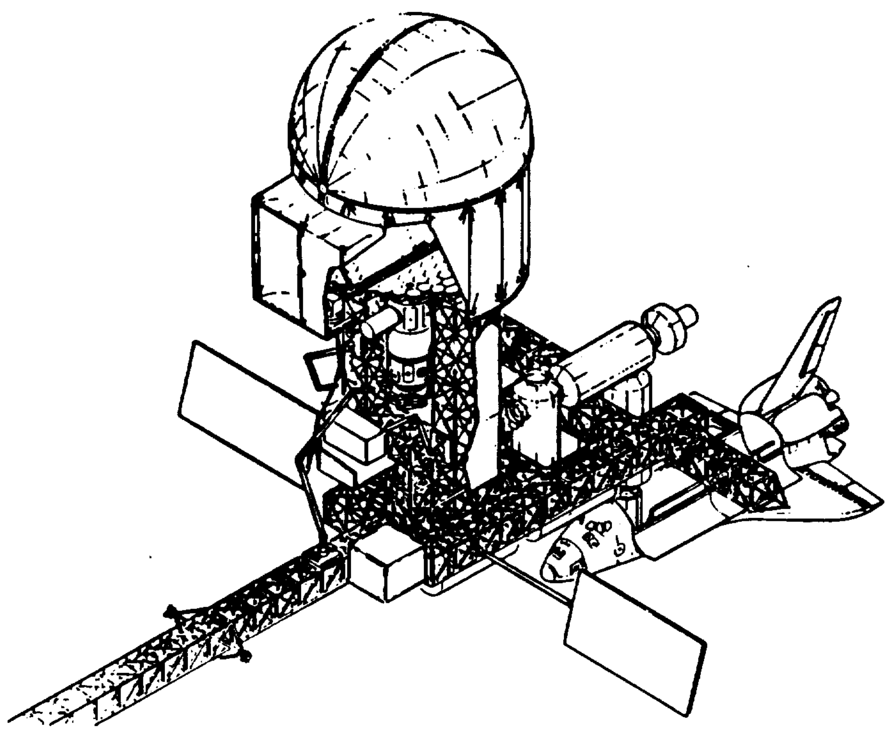
Assembly as a free flyer would decouple LDR from Space Station vibrations and remove station imposed orientation constraints. It would also isolate it from Space Station contamination sources. However, it would probably receive more contamination from the STS. It would also require that a spacecraft be available at the beginning of the build-up process to serve as the basic building block, provide attitude control and power. Spacecraft expendables would be used throughout the build-up process requiring "top-up" before final deployment. Further, the build-up process would be isolated from all of the robotics assembly/checkout aids, and EVA/IVA capabilities available at the Station. Assembly would be more difficult and greater risk would be involved.

Tethering LDR to the station would retain some of the advantages of vibration, pointing and contamination isolation offered by the free flyer option while making it more convenient to return the LDR to the station. Power could be transmitted from the station through the tether. However, a device of the size and weight of LDR tethered to the station would have a significant impact on Space Station dynamics and station keeping and might adversely affect the safety of Space Station operations. Major assembly aids on the Space Station would still not be available for LDR.

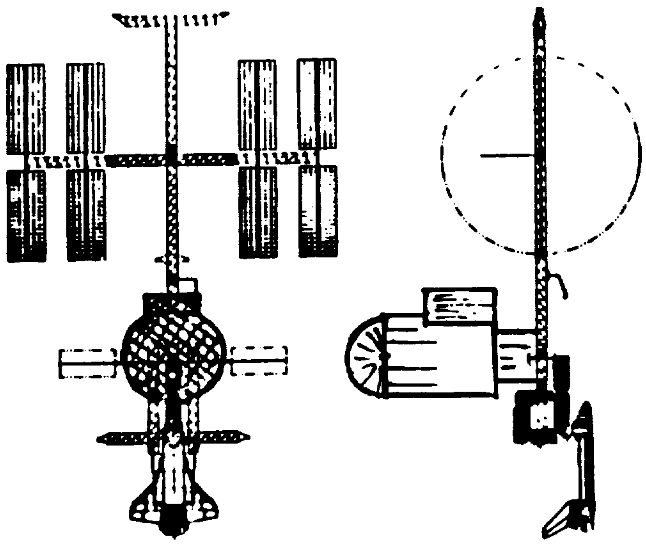
Assembly, while attached to the station, would subject the LDR to station generated contaminants but leave it relatively isolated from Shuttle contaminants, which would be significant only during approach/docking and departure of the Shuttle. Assembly would be greatly facilitated by the availability of robotics, MRMS, EVA, IVA and Laboratory Module based assembly/checkout aids. Risk would be significantly lowered. Final alignments requiring vibration isolation and star tracking would be disturbed, but these might be done in a detached station-keeping mode after assembly and checkout. Availability of station-based assembly aids would make it easier to construct a large hanger for contamination avoidance (Figure 2.2.2-1), but a smaller self-protected LDR using the LDR thermal shield as part of the contamination avoidance shroud (Figure 2.2.2-2) might be more feasible. Strippable coatings could be used to protect the surface of primary mirror segments. Assembly could be with the optical axis perpendicular to the keel (Figure 2.2.2-3) or parallel to the keel (Figure 2.2.2-4). The perpendicular configuration would require an attachment yoke but would facilitate contamination protection by the self-protected shield concept in conjunction with a reusable skirt. The yoke could be designed for use by other missions as well. The parallel concept would be more amenable to the Langley rotating axis assembly method, requiring less EVA movement by the astronant and, perhaps, less risk. It would, however, probably require a considerably larger, separate contamination shield or hanger.



CONTAMINATION - AVOIDANCE SHROUD
Figure 2.2.2-1



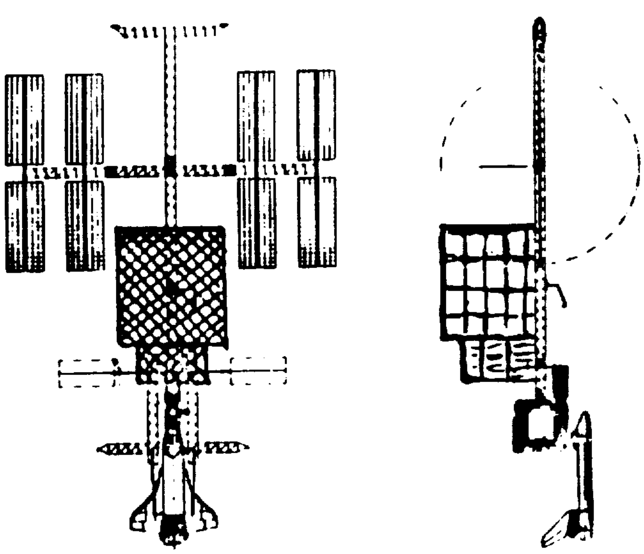
SELF-PROTECTED LDR - TOP CLOSED
Figure 2.2.2-2



- OPTICAL AXIS PERPENDICULAR TO KEEL
  - YOKE OR SPECIAL ATTACHMENT NEEDED
  - ENABLES REUSABLE SKIRT SHIELD DESIGN
  - APPLICABLE FOR USE BY OTHER PROGRAMS

LDR ON SPACE STATION - PERPENDICULAR TO KEEL

Figure 2.2.2-3



- PARALLEL TO KEEL
  - CLEARANCE
  - AMENABLE TO ROTATING-AXIS ASSEMBLY CONCEPT FOR SEGMENTED PRIMARY MIRROR
  - SEPARATE CONTAMINATION SHIELD (OR HANGER)

LDR ON SPACE STATION - PARALLEL TO KEEL
Figure 2.2.2-4

2.2.3 Alignment and Check-Out

The final alignment and check-out, prior to placement in operational orbit, will include the following elements.

1) Major Alignments (in order)

- Primary Mirror segments to Primary Mirror Figure
- Secondary Mirror to Primary Mirror
- Scientific Instruments to focal surface
- Fine Guidance Sensor to focal surface

2) Major Optical Control/Sensor Systems Check-out

- Primary Mirror actuation
- Secondary Mirror actuation/chopping
- Scientific Instrument actuation
- Fold Mirror operation

3) Major Spacecraft Check-out

- Pointing/Control System
- Propulsion System
- Aperture Cover
- Power Subsystem/Panels
- Thermal Louvers
- Communications/Antenna
- Telemetry/Data Processing
- Command System
- Cryogenic/Thermal Control System

Freedom from Space Station vibrations and the ability to accurately point at and track selected stellar objects is a necessity for the alignments. Therefore, they must take place with the observatory removed from the station, OMV/OTV and Shuttle, in free flight. Placement in an orbit in close proximity to the station could be by propulsion supplied by the observatory spacecraft or OMV. It is expected that a desire to conserve spacecraft fuel would favor the OMV approach. Alignment and check-out could be controlled from the Space Station Lab Module, the ground, or some combination of the two. Ground control would avoid placing additional workload on the station crew. However, the station-based specialists should be suited to the task since they will have had the recent experience of performing LDR alignments and check-outs on the station during and after build-up. Further, if major problems are encountered, the station based specialists may have to handle them, after return of LDR to the station.

2.2.4 Placement in Operational Orbit

Prior to boost into operational orbit the observatory solar panels will be folded. Also, the optical and internal thermal control surfaces should be protected in some way, preferably by closing the top of the lens shade/thermal shield. Propulsion for boost into operational orbit might be supplied by a dedicated integral spacecraft or by Space Station-based OMV/OTV. A third (more costly) possibility, for maximum redundancy, would be propulsion by OMV/OTV, holding an integral spacecraft capability in reserve.

Relying solely on an integral spacecraft would present the greatest risk. However, provision could be made in this design for compatability with the OMV/OTV so that, in event of spacecraft malfunction, the OMV/OTV could be called on as a back-up. However, a failure would still present major problems since it would probably affect the spacecraft's ability to provide orbit maintenance in its operational orbit. Designing the spacecraft to provide only for orbit maintenance and attitude control, and relying on the OMV/OTV for boost/de-boost to and from operational, orbit would simplify the spacecraft and reduce its cost. The third possibility, of fully redundant boost/de-boost capability would, as indicated above, be very costly.

2.2.5 Servicing and Resupply

Servicing/resupply missions are envisioned every three years. They will be necessary to replenish cryogens and propellants and change replaceable units (ORU's), as required. This service could be supplied by an OMV/OTV with a "smart front end" utilizing tele-presence and robotics, by an STS being sent either from the Space Station or the ground or by return of the LDR to the Space Station. Use of the OMV/OTV smart front end approach would probably require the research, development and manufacture of additional specialized equipment. Still, depending on OMV/OTV and Shuttle pricing policies, it might compare favorably to use of a dedicated Shuttle. The OMV/OTV could be sent to the LDR at its operational orbit or the LDR could be decayed or adjusted to a lower orbit. LDR would have to be moved to a lower orbit to enable servicing from the STS. Returning the observatory to the Space Station would offer the greatest servicing flexibility and, probably, the least risk. Cost might also be quite low, again, depending on pricing policies. A dedicated or semi-dedicated STS from the ground would appear to be the most costly and least attractive alternative.

2.2.6 Re-configuration and Refurbishment

Functions to be performed during re-configuration and refurbishment include change-out of Scientific Instruments; replacement of mechanical refrigeration units, selected observatory subsystems and damaged or malfunctioning parts (including mirror panels) and cleaning, as required. A list of spares to be kept for this purpose should be developed during the technology development phase and refined during LDR development. Means of cleaning mirror panels in space also need to be studied. Spare parts, subsystems and SI's could be kept stored on the Space Station or brought to the Station at the time of need by a dedicated Shuttle flight. Storage allows more flexibility in Shuttle manifesting since the equipment can be brought in smaller loads over an extended period of time.

2.3 SIMPLE STRUCTURAL MEMBERS VERSUS COMPLETE SUBASSEMBLIES

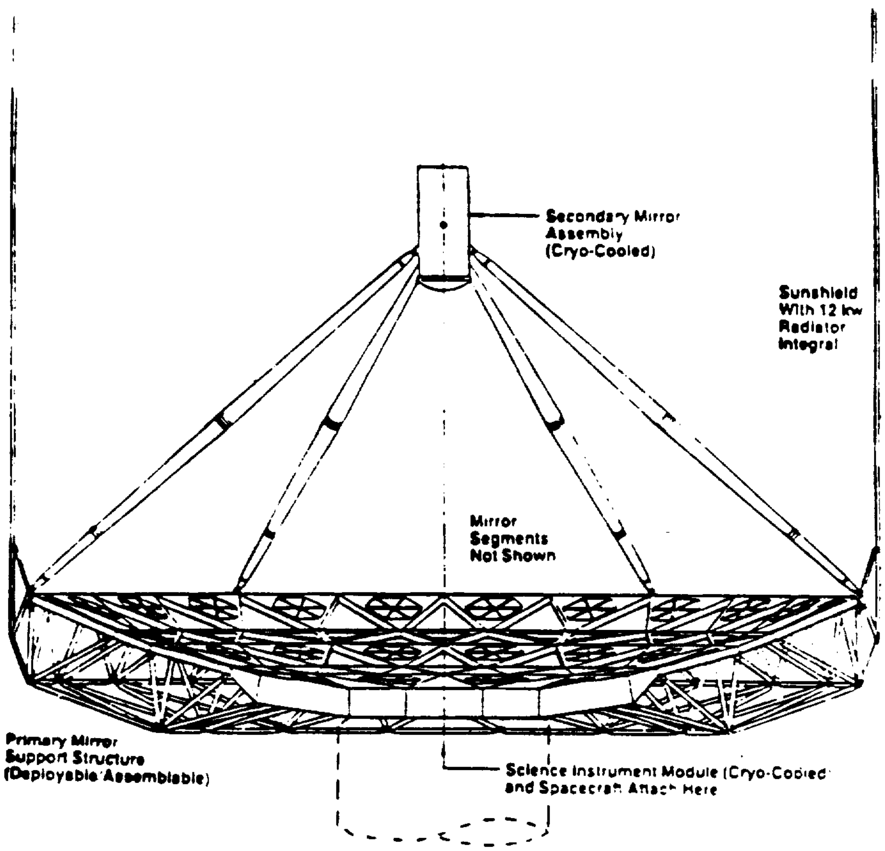
LDR will involve three very challenging structural assemblies, (1) the complete primary mirror support structure, (2) the hexapod secondary mirror support structure, and (3) the sunshield/"lens-cap" combination. Figure 2.3-1 illustrates basically the nature of these three structures (except for the lens-cap).

There are many factors which must be considered in developing an approach to constructing this complex and high performance part of LDR. Compaction for delivery in the Shuttle, time required for construction, construction crew and support equipment needs, rigidity of the final product and other factors must be considered in trading off between the two basic choices for this class of orbital construction; i.e., erection of simple structural member versus erection at a higher level of partially, preassembled subassemblies, particularly in the case of the primary mirror support structure. Figure 2.3-2 compares these two construction approaches for LDR from the aspect of various associated costs, reliability, performance, cargo delivery, ground performance assurance testing, and most importantly, predicability of end-item performance. Plus and minus marks indicate advantages and disadvantages.

Although there are attractive benefits to employing some deployable (pre-integrated) subassemblies, the three dimensional curvature and high stiffness requirements of the primary mirror support structure tend to shift the attention more to using the approach of erection of simpler structural elements. Certainly, there could be the possibility of using a hybrid approach of selectively utilizing some deployables for some portions of the structure; however, once deployed, any folding joints will most certainly have to be solidly rigidized, most optimally with a bolt, for the reasons listed.

Since there is literally no design data or experience on the erection of very high (optic) performance support structures in orbit, McDonnell Douglas has constructed applicable IRAD funded tests in their EVA man-rated underwater test facility, as indicated in Figures 2.3-3 and 2.3-4. Here, a full-size simulation of one section of the LDR primary mirror support structure was assembled, element by element and attached to three (trapezoidal-shaped) simulated mirror sections. Numerous lessons were learned in this test, timeline data were logged and concepts for LDR peculiar construction support equipment developed. Further utilization of this basic structure (and the test facility) are envisioned for testing joint rigidization, strut replacement, deformation sensor installation, mirror actuator integration/replacement, and other concepts developed by McDonnell Douglas or other organizations with LDR interest.

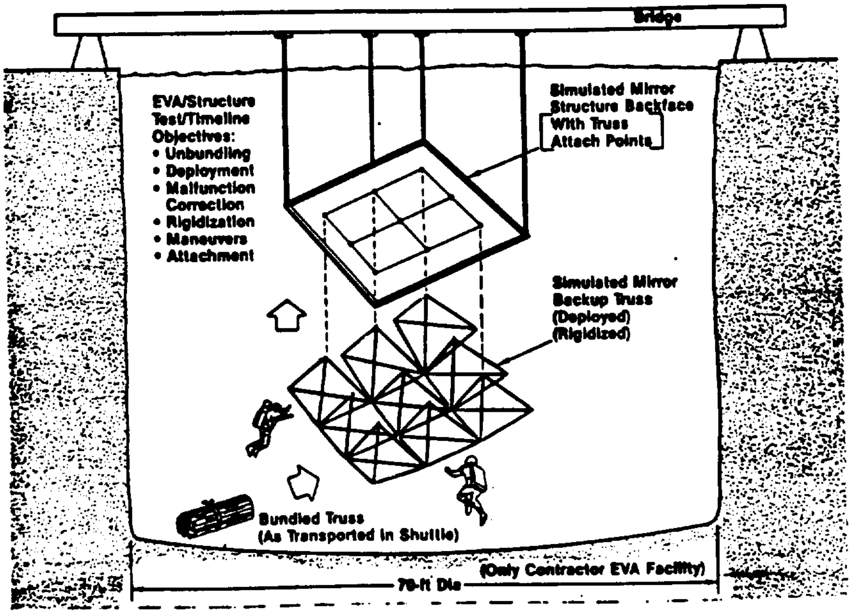
Essentially, there is considerable indication that EVA construction of much of LDR, on an element-by-element basis, is the most conservative approach to fulfilling the demanding performance requirements of LDR structure with reasonably assurable predictabiltiy. Although quickly-deployable schemes may save some construction time, the simpler element-erection approach appears to offer many more benefits. Moreover, the high-ridigity, predictable performance, and long operational life goals of LDR seem to diminish the attraction of "quick-initial-deployment."



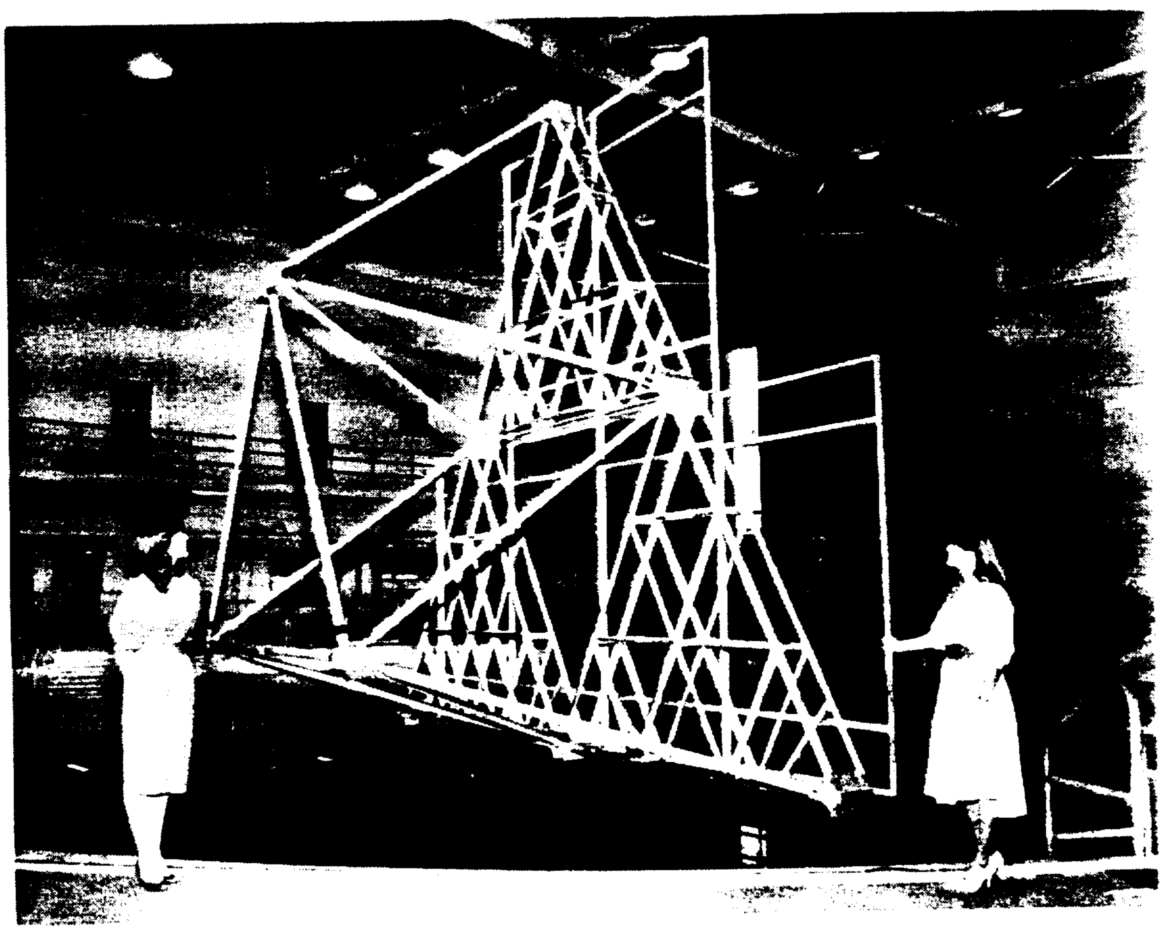
LARGE DEPLOYABLE REFLECTOR (LDR) TELESCOPE
(20 METER DIAMETER)
Figure 2.3-1

Aspect	Deployable	Erectable
■ Cost of design, test, production, handling	− (Extra parts, complex I/Fs)	+ (Basic parts only)
■ Cost of operational emplacement	+ (Semi-automatic)	− (Extensive, simple EVA)
■ Reliability of emplacement	− (Myriad moving joints, actuators) (Rigidizers, etc. total joint rec. low; hangup contingency tools needed)	+ (Simple procedure) (Highly reliable) (Predictable after ground sim)
■ Predictibility of structural performance	− (Nonlinearities galore???)	+ (Simpler structure, predictable joints)
■ Structural dynamics (payloads want quiet)	− (Required rigidizing adds complexities: automatic or EVA)	+ (Easier to make firm joints)
■ Delivery volume	− (Folding joints, actuators add volume to basic elements)	+ (Highly compactable)
■ Ground performance testing (activation, dynamics)	− (Gravity prevents valid simulation)	+ (Less unknowns to test)
■ Conservatism in concept selection	− (Many "potential" uncertainties)	+ (Many "potential" advantages)

OPTIONAL APPROACHES TO LARGE STRUCTURES
Figure 2.3-2



LDR MIRROR-BACKUP TRUSS TESTS
(IN MDAC UNDERWATER TEST FACILITY)
Figure 2.3-3



UNDERWATER TEST ARTICLE
Figure 2.3-4

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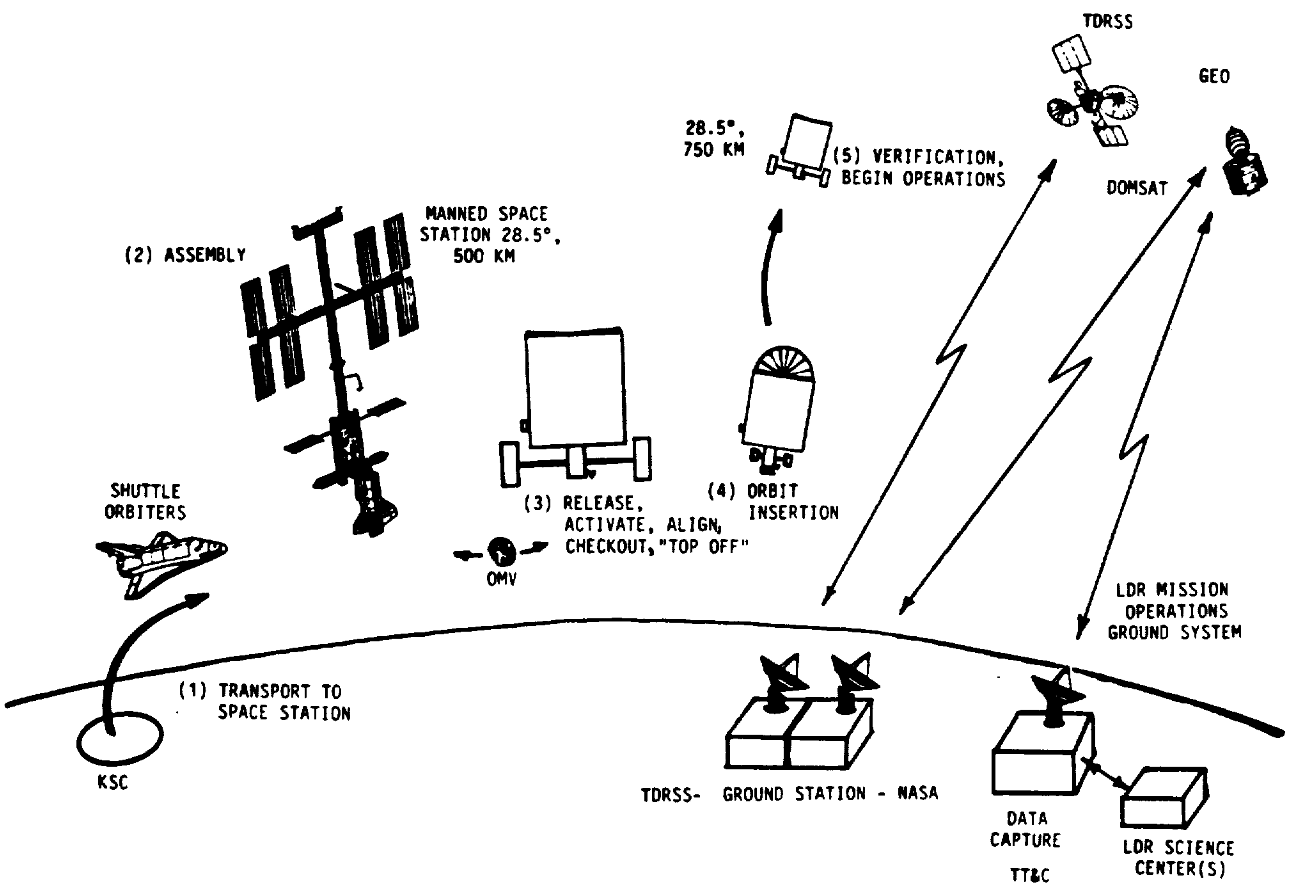
2.4 SELECTED SCENARIO

An overview of the LDR mission elements for a Space Station assembled LDR scenario is presented in Figure 2.4-1.

This section discusses aspects of each of these mission elements plus orbital resupply/servicing and reconfiguration/refurbishment.



SPACE STATION ASSEMBLED LDR
MISSION ELEMENTS CONCEPT
Figure 2.4-1

2.4.1 Transportation

Conservative analysis indicates the need for five Shuttle flights to place the LDR and related assembly and check-out aids on the Space Station. It is assumed that the station will be in a 500 km, 28.5° inclination, orbit and that the Shuttle will have a 17,250 kg lift capability to this orbit.

STS launch requirements for an example LDR flight manifest are shown in Figure 2.4.1-1. Although this example may not be fully optimized, an attempt was made to address all concerns on at least a first order basis. LDR mass is the key constraint driving the total number of STS flights. However, volume and payload center of gravity (C.G.) constraints also play a role. The need to have certain items available at a particular point in the assembly process is also a major consideration.

The so-called "Rock-of-Gibralter" central primary mirror segment and associated structure is transported on the first flight since it serves as the foundation for all construction. Similarly, lab module equipment and special tools, aids and fixtures are needed to commence construction. The Step Thermal Shield/Sunshade, Primary Mirror (PM), and Secondary Mirror (SM) Assembly carried on Flight 2 are the next major elements needed to allow continuation of construction. The Fine Guidance Sensor fills out this load. Flights 3 and 4 are devoted to carrying Primary Mirror (PM) segments and solar array panels. Each PM segment, complete with actuators and support structure, weighs 584 kg. Now, after telescope construction is complete, the integrated Scientific Instruments (SI's), their hybrid cooler, and the Spacecraft (S/C) can be added to the back of its central section. The SI's are pre-cooled on the ground and maintained in that state, until final check-out, by an auxiliary cryogenic cooler. At final check-out the prime mission cryogenic cooler is activated. This approach eliminates the need to carry the large amount of cryogens needed for initial cooldown into orbit and is one of the reasons for bringing the SI's to the Space Station last, on Flight 5. The total mass carried into orbit on these five (5) flights is approximately 52,000 kg. This excludes the assembly yoke, contamination control skirt and cabling which are assumed to be in place on the Space Station to support earlier missions.

FLT 1

- "ROCK OF GIBRALTER"
- CONVERTIBLE TOP
- LAB MODULE EQUIPMENT
- SPECIAL TOOLS, AIDS, AND FIXTURES

FLT 2

- STEP THERMAL SHIELD
- PM SUPPORT TRUSS
- SECONDARY MIRROR ASSY
- FINE GUIDANCE SENSOR

FLT 3

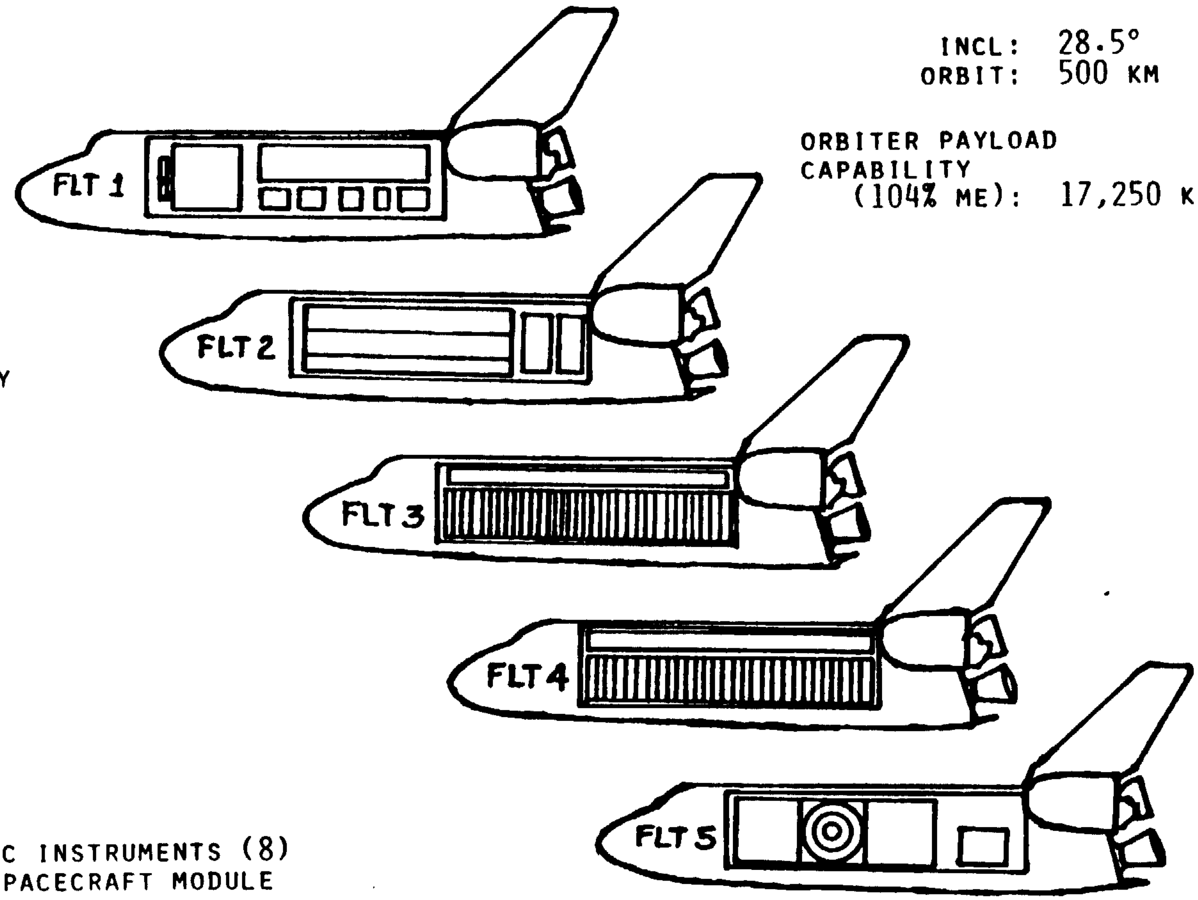
- PM SEGMENTS (30)
- SOLAR ARRAY (1)

FLT 4

- PM SEGMENTS (30)
- SOLAR ARRAY (1)

FLT 5

- INTEGRATED SCIENTIFIC INSTRUMENTS (8) HYBRID COOLER, AND SPACECRAFT MODULE
- AUXILIARY CRYOGENIC COOLER



INCL: 28.5°
ORBIT: 500 KM

ORBITER PAYLOAD CAPABILITY (104% ME): 17,250 KG

LDR LAUNCH REQUIREMENTS — EXAMPLE FLIGHT MANIFEST

Figure 2.4.1-1

2.4.2 Handling and Storage

2.4.2.1 Optional Approaches to Space Station Interfaces - Much of the LDR related handling and storage on Space Station is governed by many options which are selected for basic LDR mission accommodations. Figure 2.4.2.1-1 lists the numerous options which were considered for accommodating the broad spectrum of LDR requirements involving the Space Station and the Orbit Maneuvering Vehicle (OMV).

The approaches chosen are checked in the figure.

Construction and protection (station exterior)

Site installation
- End docking mechanism to spacecraft (surrogate OMV)
- ✓ Side trunnions to spacecraft (surrogate cargo bay)

Contamination avoidance
- Directional shield/greatest threat
- Total enclosure — separate from LDR
- ✓ Total enclosure — integrated with LDR sunshield

Construction manipulation
- MRMS and EVA
- ✓ MRMS, mini-manipulator and EVA
- No EVA (multi-manipulator)

(for MRMS options:)
- All piece parts
- Some deployable portions

Cargo/work site transfer
- Enclosed parts — transfer in open to airlock
- Enclosed small modules of parts — transfer in open to airlock
- ✓ Enclosed large modules of parts — attach direct to airlock

Monitoring and control
- Use Space Station work station and data/comm subsystems
- ✓ Use LDR-peculiar rack equipment delivered with LDR

Crew involvement
- ✓ LDR specialist(s) with station core crew
- Station core crew only

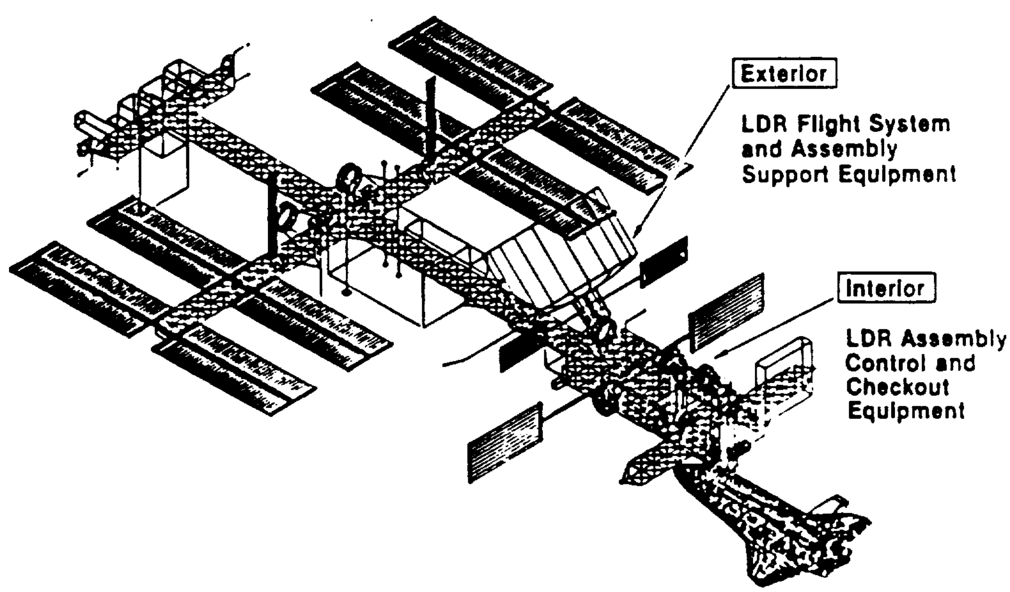
Final checkout
- On station
- ✓ Off station and return for final prep
- Off station and then to operational altitude
- Tethered to station

Periodic servicing
- ✓ Via OMV/smart kit, and tanker or mini-logistics module
- Via OMV/smart kit and individual ORU
- Return to station
  - Docked
  - Proximate for EVA and/or OMV/smart kit servicing

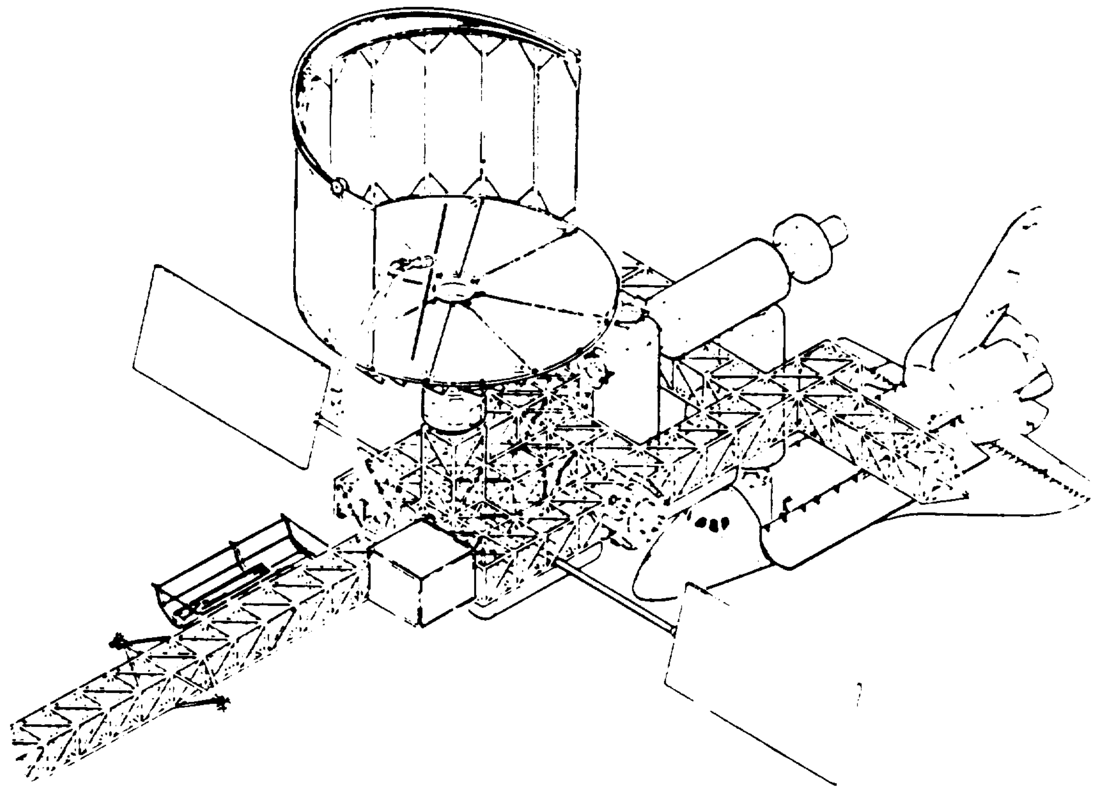
OPTIONAL APPROACHES TO LDR/SPACE STATION INTERFACES
Figure 2.4.2.1-1

2.4.2.2 Handling and Storage Approach - Once LDR elements have been delivered to the Space Station by the Shuttle, they are removed directly from the Shuttle cargo bay by the mobile remote manipulator system (MRMS) on the station, or transferred by the Shuttle remote manipulator system, out of the cargo bay, to the MRMS. Next, the LDR equipment, (which will be either the spacecraft, the instruments or unit packaged parts, in an open pallet or, in an enclosed container if environmentally sensitive), will be moved to the large mission assembly and test site by the MRMS and stowed. The spacecaft unit and the instrument unit (the first items delivered) will be mounted between a set of beams which simulate the Shuttle cargo bay, with the forward end open for LDR buildup. Next, pallets or containers with subsequent equipment will be temporarily stowed slightly off-site, on the keel, using the same side-mounted trunnions that were used for stowage in the Shuttle cargo bay.

After the spacecraft and instrument units are in place, pallets containing the primary mirror support structure and the sunshield/lens cover elements will be delivered, stowed, unloaded and returned to the Shuttle loading area. A temporary mirror transfer access port will also be delivered at this time via pallet and attached to the side of the LDR sunshield to environmentally protect the mirrors delivered subsequently, and transfer from their environmental container into the interior of the LDR for mounting. Figures 2.4.2.2-1 and 2.4.2.2-2 illustrates the overall equipment arrangements inherent in the early handling and storage of LDR components during its construction.

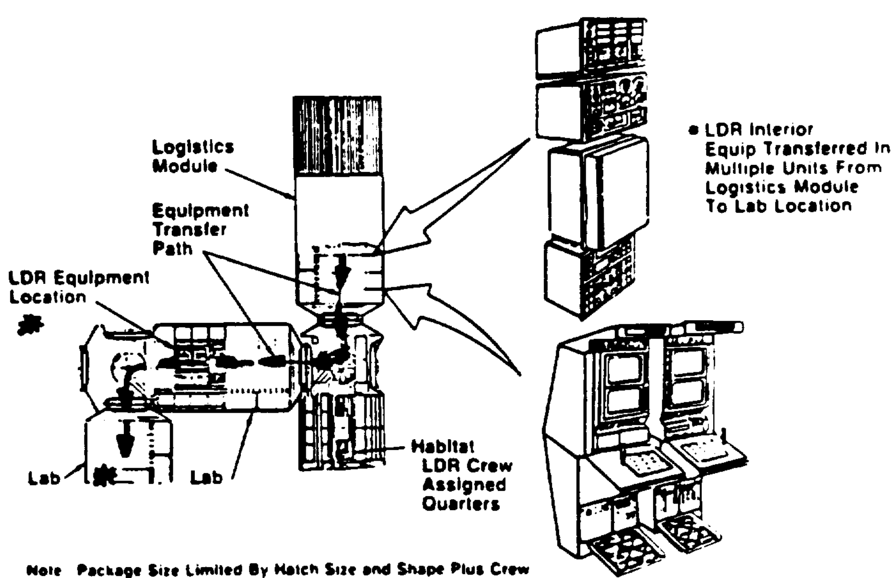


LDR ON SPACE STATION
Figure 2.4.2.2-1

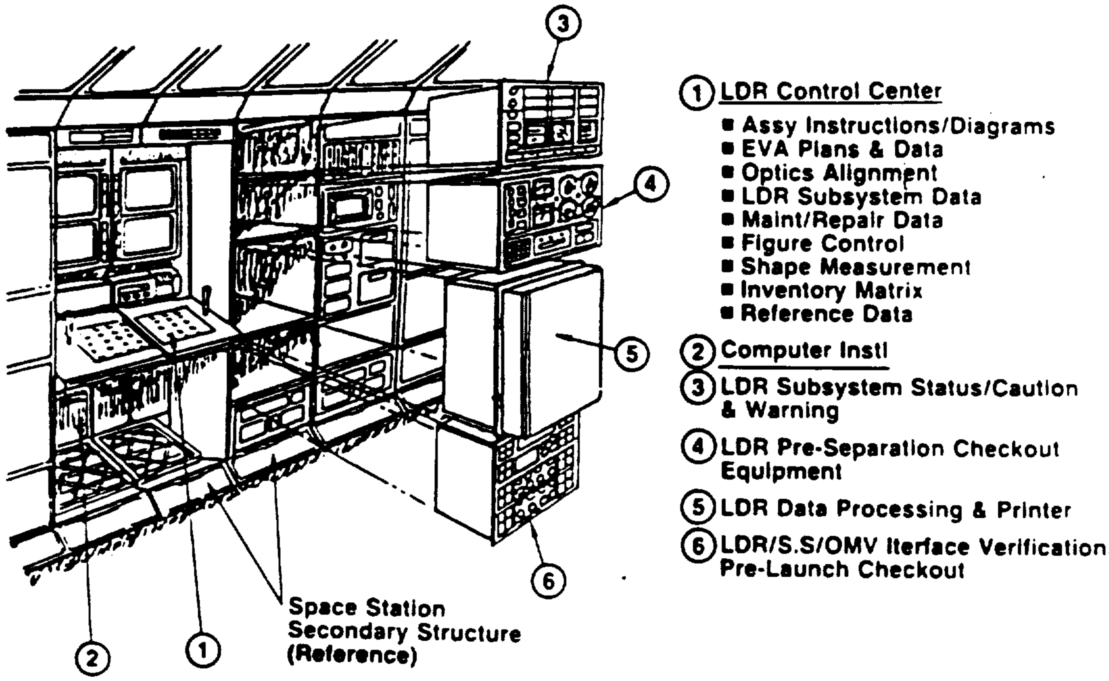


INITIAL LDR CONSTRUCTION/SELF ENCLOSURE
Figure 2.4.2.2-2

Figure 2.4.2.2-3 illustrates the process plan for delivery of the LDR equipment destined for station module interior mounting, and Figure 2.4.2.2-4



LDR INTERIOR EQUIPMENT DELIVERY LOGISTICS
Figure 2.4.2.2-3



LDR INTERNAL CONTROL CENTER
Figure 2.4.2.2-4

illustrates an early concept of the type of console/rack equipment required for controlling, monitoring, analyzing LDR buildup and preliminary check-out, and finally launching it from the station. Such equipment would, after LDR final launching to operational altitude, be returned to Earth to make room for some other station mission equipment.

2.4.3 Assembly

A broad overview list of the elements and resources required to assemble or construct LDR on the Space Station is given in Figure 2.4.3-1. Figure 2.4.3-2 illustrates the logistics support scenario which will provide the flow of LDR specialists, interior and exterior equipment and, during LDR solo flight, the replacement and replenishment items for continuing maintenance. Maintenance may be provided remotely, via OMV, or on-site, for very major overhauls.

Once the LDR spacecraft is in place on the station, the first load of sunshield/aft enclosure build-up elements are delivered and stowed nearby, as described in 2.4.2. The assembly process is initiated with the MRMS acting in coordination with EVA crew members. Individual elements, which are all coded, are extracted from their carrier, moved to the intended final position and secured via EVA manual and tool supported operations. Figures 2.4.3-3 and 2.4.3-4 illustrate the sequence and applicable relationships inherent in this activity. The first objective (upper left of figure) is to build a total environmental enclosure, using the sunshield, an aft thermal enclosure,

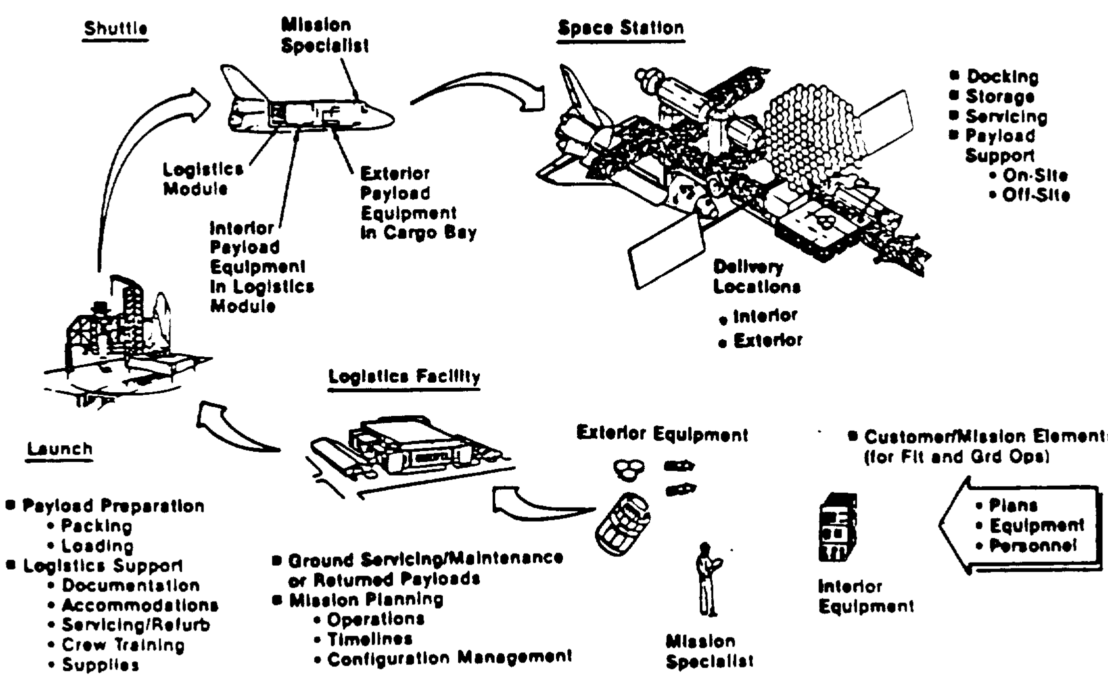
Elements

- Spacecraft
- Science Instrument Module + Core Primary Mirrors
- ~50 Primary Mirrors + Individual Delta Frame Assemblies
- ~50 Primary Mirror Support Trusses (Bundled)
- Secondary Mirror and Support Equipment Module
- Secondary Mirror Hexapod + Metering Rods
- ~6 Sunshield Frame
- ~6 Sunshield Panels
- ~2 Sunshield Attached Radiators

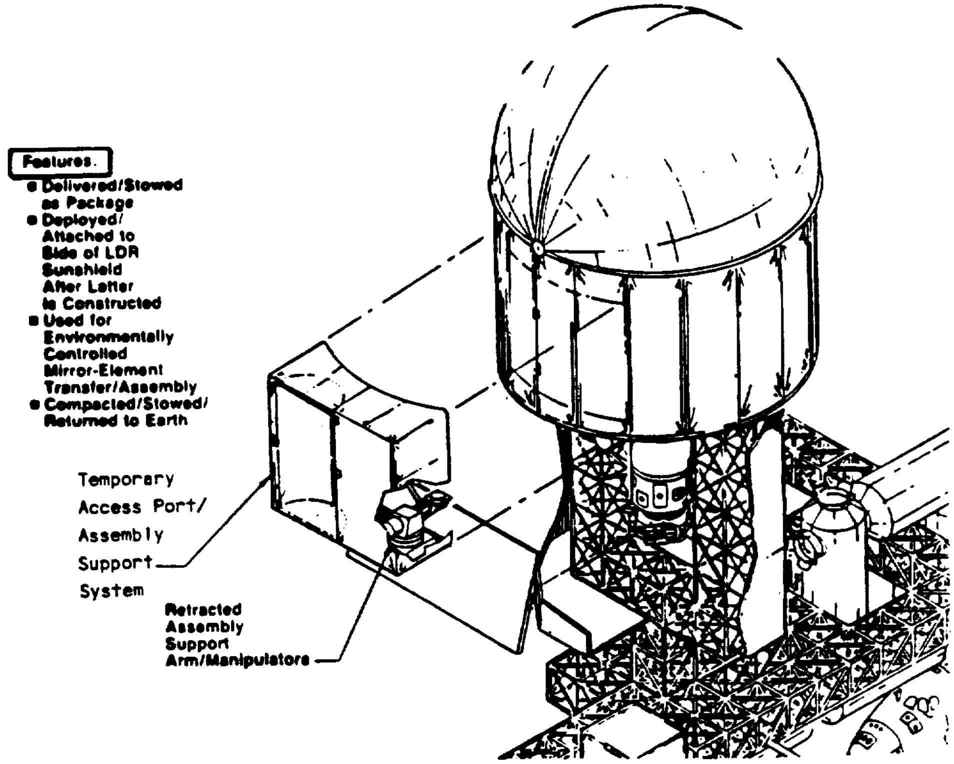
Resources

- Space Shuttle (Transport)
- Space Station (Construction, Checkout, Launch and Servicing)
- Space Station Core Crew Support
- LDR Special Crew
- EVA Aids and Tools
- Interior Control and Monitoring Consoles
- Exterior Stowage, Holding Fixtures, Hangar and Work Stations

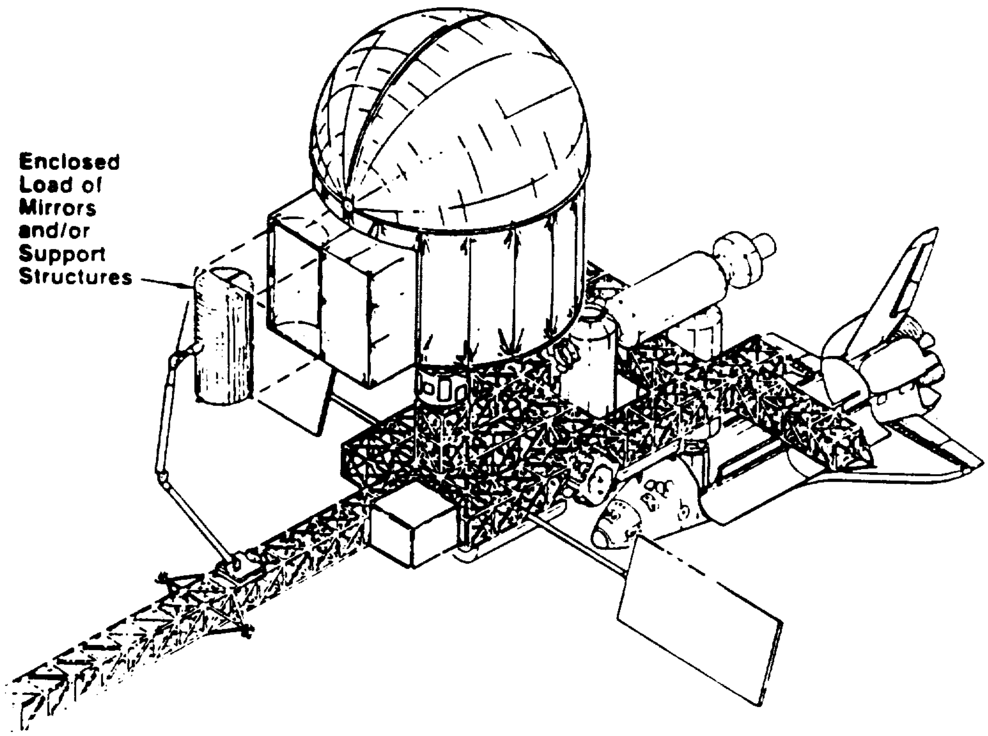
LDR CONSTRUCTION OVERVIEW
Figure 2.4.3-1



LOGISTICS SUPPORT SCENARIO
Figure 2.4.3-2



ENVIRONMENTAL PROTECTION FOR MIRROR TRANSFER
Figure 2.4.3-3



SELF-PROTECTED LDR - LOAD INSERTION
Figure 2.4.3-4

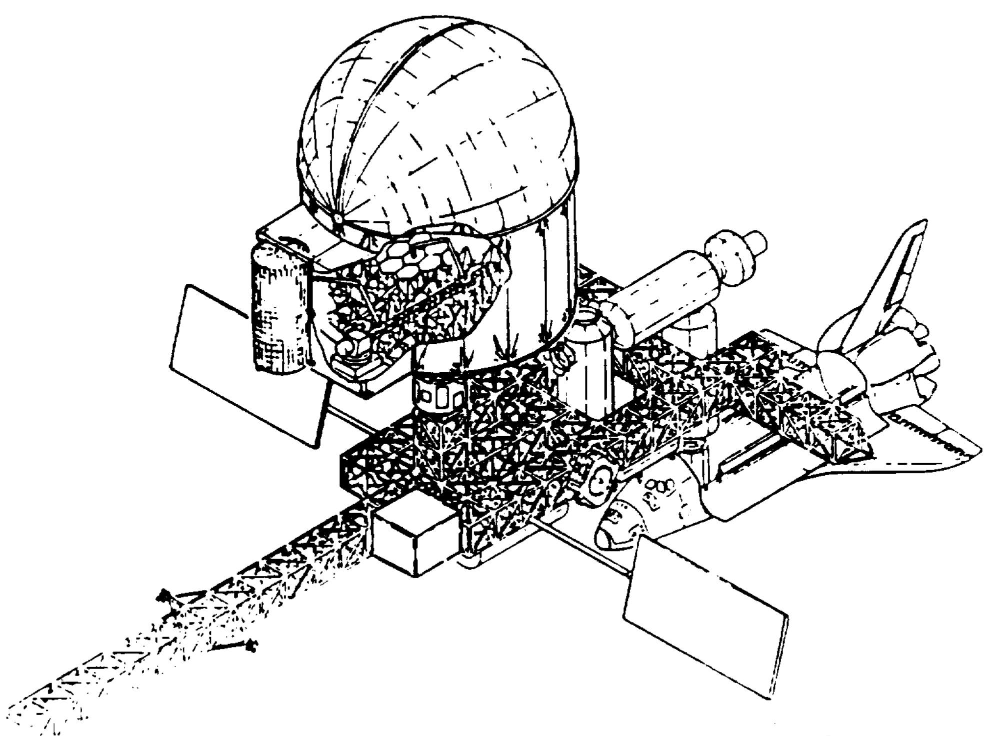
and the convertible top "lens cap" as elements and adding a temporary access port for the subsequent transfer for all remaining parts delivered in enclosed containers.

Exterior-Configuration Envelope

As shown, after the LDR elements are assembled and the airlock is added, mirror support structural elements, primary mirror segments, the secondary mirror unit and its hexapod supports are delivered, transferred to, and assembled inside the LDR using a special manipulator/EVA combination. In this manner, all LDR elements which are sensitive to Space Station, Shuttle, OMV, OTV or other leakage outgassing contaminants, will be protected during handling and installation (see Figure 2.4.3-5).

When construction is complete, the special manipulator is removed, followed by the temporary airlock. Both are stowed using the MRMS, in the carrier unit in which they will ride back to Earth in the Shuttle.

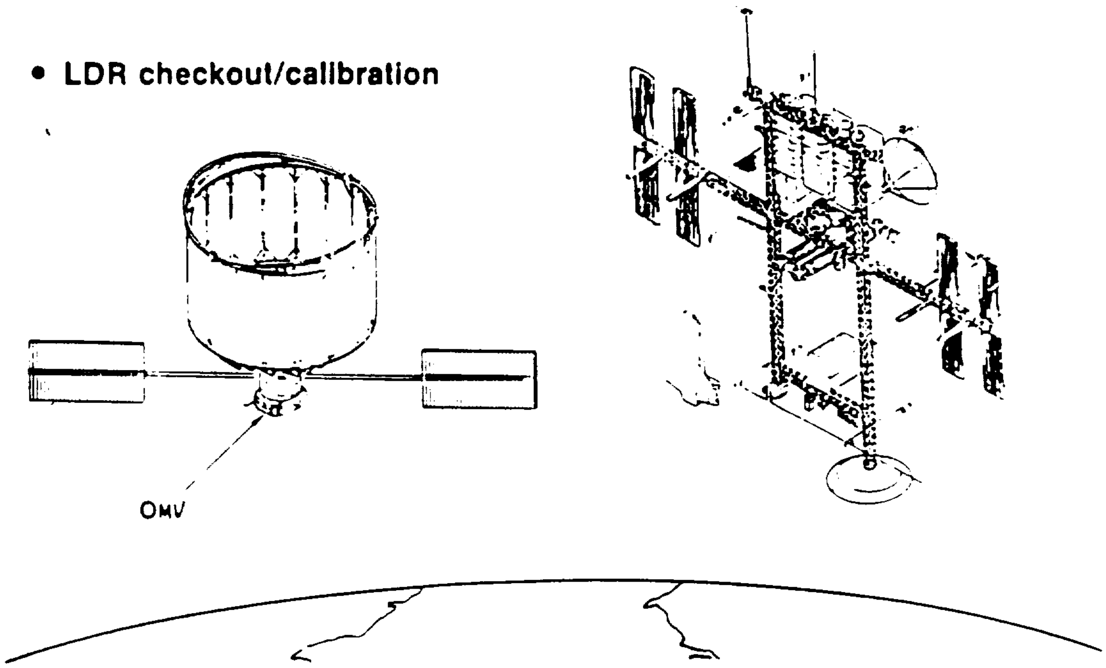
The primary mirror truss elements will be assembled, primarily by EVA, based on coded markings on the elements and instructions. Once the support structure is complete the primary mirror segment units will be installed by bolts or highly rigidized latches at intersections of the supporting truss members. Next the hexapod support columns of the secondary mirror unit will be erected and topped by the secondary unit. Next all utilities will be installed, i.e., cables and tubing for data, power and thermal provisions, all by EVA. The radiators, which are attached to the outsides of the sunshield, will then be connected with the interior coolant distribution lines. Finally, instrumentation for deformation sensing and alignment will be added by EVA.



INTERIOR MANIPULATION/ASSEMBLY OF LDR MIRROR
Figure 2.4.3-5

Outside of the vehicle, the one meter boresighting telescope will be attached to one side of the sunshield supports. The solar panels are presumed to be part of the spacecraft and thus delivered early. Most probably, the spacecraft will be operated primarily on Space Station "facility" power, except for on-site check-outs.

When the assembly is complete and all check-outs that are possible on the station are complete, the OMV will be attached to the LDR and the combination will be launched from the station to some off-site full-system optical check-out/calibration facility (see Figure 2.4.3-6). Subsequent to this, the LDR may be brought back to the station for "topping" of cryogenics before being sent to its final operational orbit.



LDR PROXIMITY OPERATIONS WITH SPACE STATION
Figure 2.4.3-6

2.4.3.1 LDR Assembly Sequence/Schedule - The Space Station supported LDR assembly, in the '97-'98 timeframe, will have a substantial impact on the payload logistics and operation world. The major aspects of the assembly sequence are identified in Figure 2.4.3.1-1. The assembly operation is divided into five phases that roughly correspond with the five Shuttle launches required to deliver the assembly support equipment and LDR components. These five delivery launches will take place over a 12-month period and not on consecutive launches (assumed every 30 days) because of station logistics and other mission launch requirements. The actual assembly, will be performed in 100 operational days during the 12-month assembly period requiring approximately 250 IVA and 450 EVA hours.

- **Five shuttle launches over 9-12 months (due to SS logistics and other mission launch requirements that restrict LDR launch schedule)**
- **Approximately 100 operational days to perform assembly, checkout, and deployment over the 9-12 months**
- **250 IVA and 450 EVA crew hours to support assembly**
- **LDR assembly phases**
  - **Buildup of assembly support (protective) system**
  - **Deployment and assembly of primary mirror**
  - **Deployment and attachment of secondary mirror**
  - **Attachment of instruments and spacecraft**
  - **Consumable supply, checkout, and orbit boost**

LDR ASSEMBLY SEQUENCE
Figure 2.4.3.1-1

Assembly Phases

The LDR build-up consists of five unique phases of operations which are scheduled over the 12 months and supported by the five Shuttle delivery flights (not corresponding).

I) Assembly support system build-up (Flight 1) - The protective hangar, equipment airlock, platforms and manipulators used to house the LDR assembly operation.

II) Primary Mirror Assembly (Flights 2, 3) - The deployment, assembly, and attachment of the major portion of the LDR.

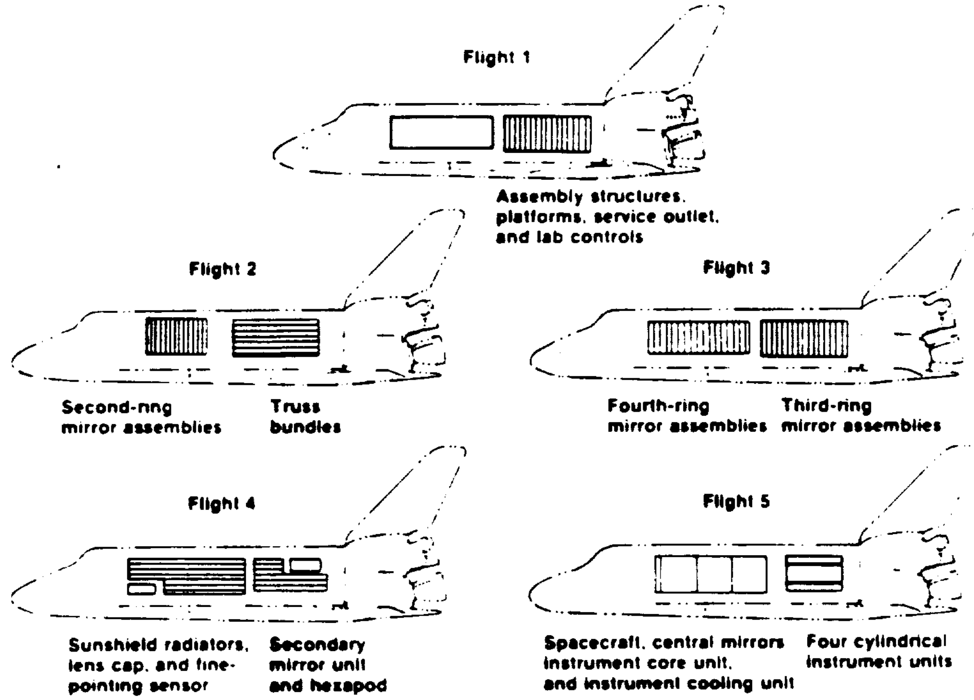
III) Secondary Mirror Assembly (Flight 4) - The deployment and attachment of the secondary mirror.

IV) Instrument/Spacecraft Attachment (Flight 5) - The spacecraft subsystem and instrument packages.

V) Boost to Orbit - The final check-out, test, consumable supply, and deployment into operational orbit.

LDR Shuttle Loads (Assembly Support)

The five Shuttle loads required to support LDR assembly, Figure 2.4.3.1-2, are scheduled around station logistics and other mission flights to conveniently support the five phase assembly sequence. The cargo manifests are shown in the figure and these correspond to the assembly phases as previously discussed. Shuttle manifesting and on-schedule delivery of components is



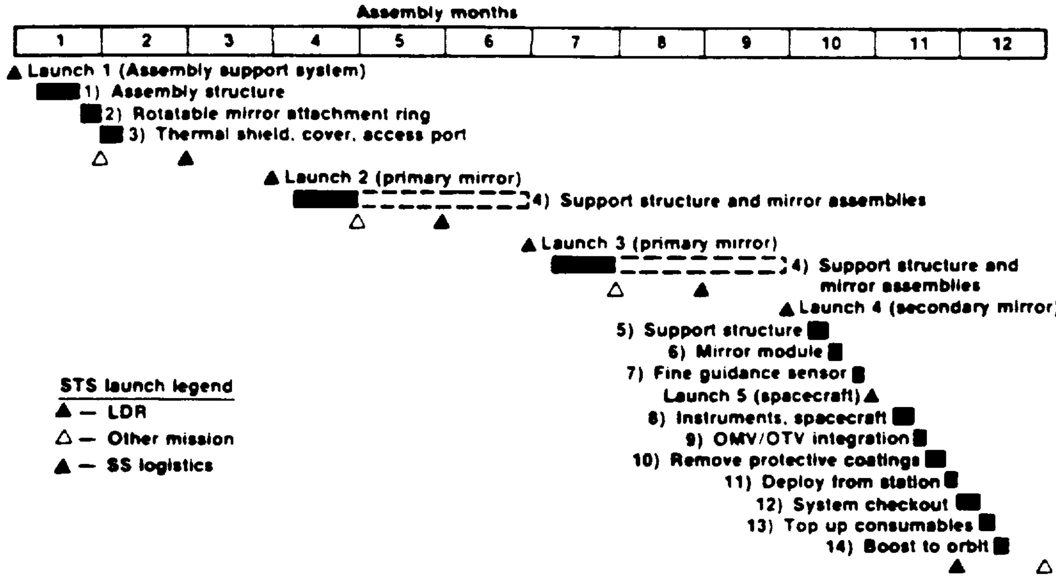
LDR SHUTTLE LOADS
Figure 2.4.3.1-2

extremely critical during the assembly sequence in order to minimize on-station duration and thus costs to park the LDR. The Shuttle manifests and their role in the assembly sequence is as follows:

	Manifest	Assembly Phase
Flight 1	Assembly structures, platforms service outlet, and lab controls	I
Flight 2	Secondary mirror assemblies, truss bundles	II
Flight 3	Third-ring mirror assemblies, fourth-ring mirror assemblies	II
Flight 4	Secondary mirror unit and hexapod, sunshield radiators, lens cap, and fine-pointng sensor	III
Flight 5	Spacecraft, control mirrors, instrument core and cooling units, cylindrical instrument units	IV, V

Assembly Timeline

The LDR assembly timeline, Figure 2.4.3.1-3, illustrates the 12-month scenario in which Shuttle deliveries are integrated with the 5 phases of LDR build-up. For this effort, it was assumed that a Shuttle would be available for launch every 30 days, every 90 days the Shuttle would be required for the Space



LDR ASSEMBLY TIMELINE
Figure 2.4.3.1-3

Station logistics flight, and that other mission flight requirements would prohibit 5 consecutive LDR flights. These assumptions necessitated an LDR assembly timeline which is stretched over many more than the optimal 5 months. The generated timeline maximizes LDR assembly within the bounds of the station parameters. There are two important aspects of this timeline that make it optimal for LDR assembly: (1) the most time critical and variable operation - Primary Mirror Assembly - has the flexibility to be performed over a six-month period as Space Station resources and schedules allow, and (2) launches 4 and 5 are back-to-back to allow for the final assembly and deployment to be as rapid as possible.

Assembly Requirements Matrix

The requirement matrix, Figure 2.4.3.1-4, shows the 14 step 100 day assembly process and the associated requirements for each assembly task. It is clearly evident that Step 4 - Primary Mirror Assembly, is the most critical in terms of launches (2), crew hours (100 IVA, 250 EVA), support equipment, and operational days (45) requirements. This matrix will serve as the baseline in all future studies as the support requirements list. The crew hours, task duration, and detailed tools and test equipment definition will evolve from a master requirements matrix.

STS Flight	Step	IVA (hr)	EVA (hr)	Special Tools	Test Equip	Oper Days
1	1. Assemble, install, and prepare assembly structure (yoke, skirt, platforms, service outlets, internal lab controls)	20	50	X		15
	2. Install rotatable mirror attachment ring ("Rock of Gibraltar")	8	16			4
	3. Assemble and attach thermal shield, cover, access port, platforms	20	24			5
2,3	4. Deploy and assemble support structure and mirror assemblies (truss bundles, ring mirror assemblies)	100	250	X	X	45
4	5. Assemble and attach secondary mirror support structure	8	16	X		5
	6. Attach secondary mirror module	4	8		X	2
	7. Install fine guidance sensor	4	8		X	2
5	8. Attach and checkout scientific instruments, spacecraft, and cryogenics	24	24	X	X	5
	9. Mate with OMV or OTV	12			X	1
	10. Remove protective coating, perform system checks	24	24			5
	11. Move away from space station	12	4			1
	12. Align and check out	24			X	5
	13. "Top up" expendables (cryogenics, propellant)	12	12		X	2
	14. Boost to operational orbit	12			X	3
	Totals	284	436			100

LDR ASSEMBLY REQUIREMENTS MATRIX
(ASSEMBLY, CHECKOUT, AND DEPLOYMENT - 100 DAYS)
Figure 2.4.3.1-4

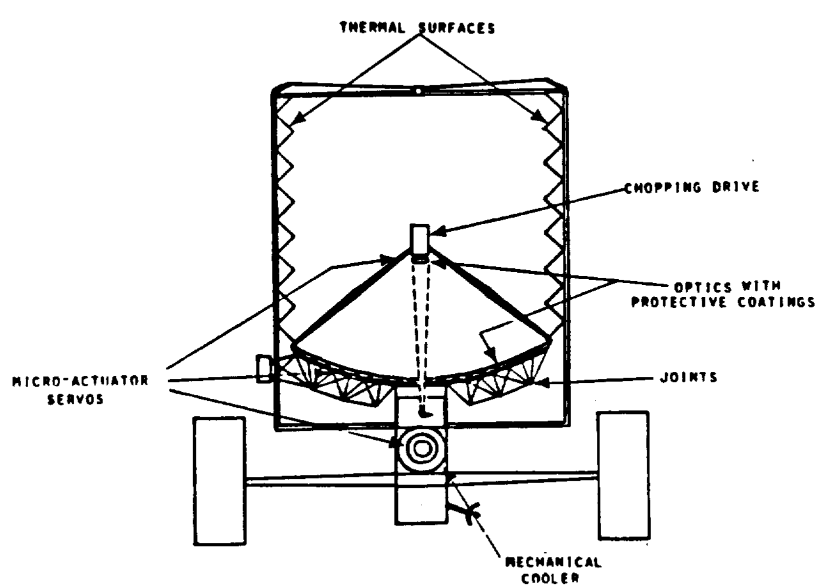
2.4.4 Checkout

Key areas that must be looked at during post assembly checkout are shown in Figure 2.4.4-1. Their positions on the observatory are shown in Figure 2.4.4-2.

The first step after assembly, prior to active testing, is to perform a complete visual inspection of all key areas including joints, thermal surfaces, electrical connections and optical components. It is possible that some areas can be checked using remote teleprescence and robotic devices. However, the added assurance of "hands-on" inspection through astronaut EVA will generally be required. This will take about 12 person - hours of EVA for a team of astronauts supported by an additional person inside the Lab Module (6 hours of IVA).

- VISUAL INSPECTION
  - JOINTS
  - THERMAL SURFACES
  - ELECTRICAL CONNECTIONS
  - OPTICS
- ELECTRICAL TESTS
  - SERVO MOVEMENT/SENSOR RESPONSE
  - POSITIONING CONTROL ELECTRONICS
  - CHOPPING DRIVE/SENSORS
- THERMAL TESTS
  - TEMPERATURES
  - FLUID FLOW
  - MECHANICAL COOLER
- MECHANICAL TESTS
  - STRESS/STRAIN
  - DAMPING
- OPTICAL TESTS
  - REMOVE PROTECTIVE COATINGS
  - INSPECT SURFACES
  - MEASURE REFLECTIVITY

POST-ASSEMBLY CHECKOUT
Figure 2.4.4-1



CHECKOUT
Figure 2.4.4-2

Functional tests will be highly automated. This will help reduce the many demands on astronaut and facility time. Electrical, thermal and mechanical tests on the telescope will take only about 48 person - hours of IVA time. Complete functional testing of the spacecraft, however, will have to await removal of the observatory from the station, deployment of solar panels and activation of the attitude control and communication subsystems.

The last steps, preparatory to removing LDR from the station, will be removal of protective coatings from the optics. This will again require EVA for astronaut operation and monitoring of semi-automatic coating removal devices. After removal the optical surfaces will be inspected, and perhaps reflectance or other measurements taken to serve as a baseline for calibration. Special equipment required for check-out and total crew requirements are shown in Tables 2.4.4-1 and 2.4.4-2.

Power consumption requirements for the LDR during check-out will be about 4,000 watts, maximum. The major portion of the total demand is 2,900 watts required to drive the cryogenic thermal cooling device to maintain the Scientific Instruments near operating temperature. Another 625 watts is needed to heat the primary mirror to maintain it at operating temperature. Other power consumption needs total about 560 watts, maximum. Power needs, by subsystem, are shown in Table 2.4.4-3.

TABLE 2.4.4-1
CHECKOUT SPECIAL EQUIPMENT

- POWER AND DATA TRANSMISSION CABLES
- TEST EQUIPMENT IN LAB MODULE
- SUPPORT YOKE, SKIRT, AND JACK
- CONSTRUCTION TOOLS AND RESTRAINTS
- TOOLS TO UNSTRIP MIRROR PROTECTIVE COATINGS

NOTE: RAW DATA ALSO TRANSMITTED TO GROUND FOR RECORDING AND FURTHER ANALYSIS

TABLE 2.4.4-2
CHECKOUT CREW

• VISUAL		
- EVA - 2 PERSONS X 6 HOURS	=	12 PERSON-HRS.
- IVA - 1 PERSON x 6 HOURS (WITH MRMS, TELEOPERATOR AND ROBOTICS)	=	6 PERSON-HRS.
• ELECTRICAL		
- IVA - 2 PERSONS X 12 HOURS	=	24 PERSON-HRS.
• THERMAL		
- IVA - 2 PERSONS X 6 HOURS	=	12 PERSON-HRS.
• MECHANICAL		
- IVA - 2 PERSONS X 6 HOURS	=	12 PERSON-HRS.
• OPTICAL - REMOVE COATINGS		
- EVA - 2 PERSONS X 1/2 HR./SEG. (WITH MRMS)	=	60 PERSON-HRS.
• CONTINGENCY - @ 100%	=	126 PERSON-HRS.
TOTAL	=	252 PERSON-HRS.

TABLE 2.4.4-3
CHECKOUT POWER CONSUMPTION

• SERVO AND POSITION CONTROL ELECTRONICS	150 WATTS
• MULTIPLEXING	100 WATTS
• DEMULTIPLEXING (IN LAB MODULE)	100 WATTS
• THERMAL CONTROL OF TELESCOPE AND SI'S	
- PRIMARY MIRROR HEATERS	625 WATTS
- COOLING	2,900 WATTS
• CHOPPING	10 WATTS
• SPACECRAFT	200 WATTS
TOTAL	4,085 WATTS

Data transmission rates will range from about one Sample-Per-Second (SPS) for thermal data to 100 SPS for some complex electronic control signals. The maximum total data transmission rate required will be about 159 KBPS. In addition, it is assumed that video and voice capability will be available to support EVA. A breakdown of data transmission needs is shown in Table 2.4.4-4.

TABLE 2.4.4-4
CHECKOUT DATA/COMMUNICATIONS

OBSERVATORY	
• SERVOS AND POSITION SENSORS	100 KBPS
• THERMAL	2 KBPS
• CONTROL ELECTRONICS	17 KBPS
• MECHANICAL	64 KBPS
• SPACECRAFT	16 KBPS
	199 KBPS
ASTRONAUT SUPPORT	
• VIDEO	~10 MHZ
• VOICE	~ 5 KHZ

2.4.5 Alignment

After on-board ckeckout is complete LDR will be jacked up in its yoke and an OMV will be attached. LDR will be separated from the Space Station and parked nearby, flying in formation with the station. Solar panels will be deployed and all spacecraft systems activated. Alignment will begin after proper operation of spacecraft subsystems is verified. It can not proceed until a stable, properly operating platform is achieved.

Alignment is a three-step process.

1) Parabolize Primary Mirror
2) Align Secondary Mirror to Primary Mirror
3) Align and Focus Scientific Instruments

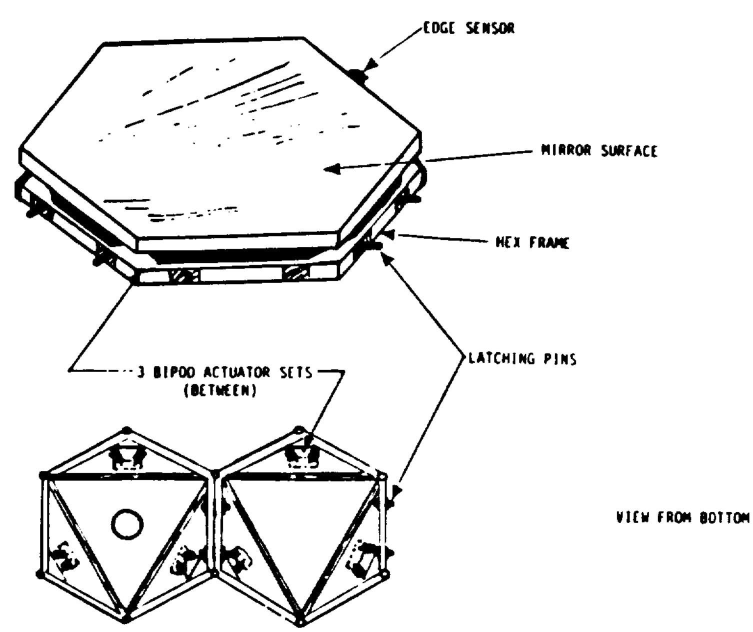
Each step must be completed satisfactorily before the next can be started.

In the alignment concept, the optics are initially aligned on the ground using air bags to achieve a simulated "o-g" condition. Individual adjustment actuators are set at the midpoint of their range and individual segments are located (with respect to each other) for optimum performance and joined. Individual segments are then detached, using simple latching mechanisms, and rejoined during Space Station assembly using the same latching mechanisms.

Functional performance of adjusting micro-actuators (servo mechanisms) and associated control electronics is verified during check-out on the station. When the free-flying observatory has achieved a stable position near the Space Station, the segments will be adjusted using their micro-actuators and rigid body control to once again duplicate their optimum position achieved during ground simulation. The Primary Mirror and a Secondary Mirror position are sensed using self-contained metric means. The Scientific Instruments are adjusted, with respect to the telescope image topography, by viewing selected stellar features.

2.4.5.1 <u>Parabolize Primary Mirror</u> - As previously indicated each of the Primary Mirror segments must be adjusted, in piston and tilt, with respect to other segments to reestablish the parabolic shape achieved on the ground. Edge position is sensed and the segments are driven to the correct positions by six micro-actuators. The configuration of the Primary Mirror segments is shown in Figure 2.4.5-1.

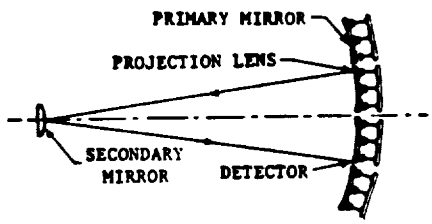
1. PARABOLIZE PRIMARY MIRROR
   - MONITOR OUTPUTS FROM MIRROR EDGE SENSORS MICRO-ACTUATORS AND PRIMARY MIRROR CONTROL ELECTRONICS. ADJUST FOR CORRECT POSITIONING OF MIRROR SEGMENTS.



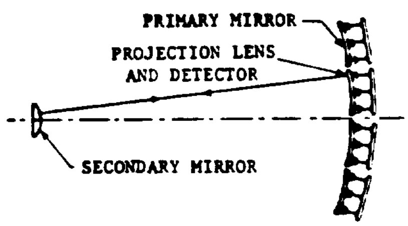
ALIGNMENT SEQUENCE
Figure 2.4.5-1

2.4.5.2 <u>Align Secondary Mirror to Primary Mirror</u> - The Secondary Mirror alignment mechanisms are shown in Figure 2.4.5-2. Laser diodes and quad cell detectors are located in the Primary Mirror. Laser beams are reflected from the center of the Secondary Mirror to detect tilt (1st) and from an off-center position to detect decenter (2nd). Six micro-actuators behind the Secondary Mirror are used to drive it in five degrees of freedom (2 tilts, 2 decenters, 1 despace) to duplicate the ground established best alignment position sensed by the quad cell detectors.

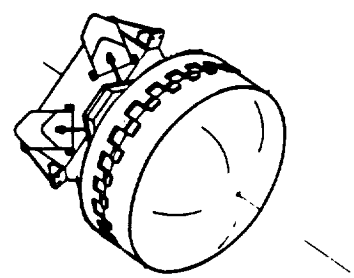
2. ALIGN SECONDARY MIRROR TO PRIMARY MIRROR
- LASER DIODES AND QUAD DETECTORS MOUNTED IN PRIMARY MIRROR PROVIDE TILT AND DECENTER SIGNALS. DRIVE SECONDARY MIRROR TO BEST ALIGNMENT.



LOCATION OF SECONDARY MIRROR TILT SENSOR



LOCATION OF SECONDARY MIRROR DECENTER SENSOR

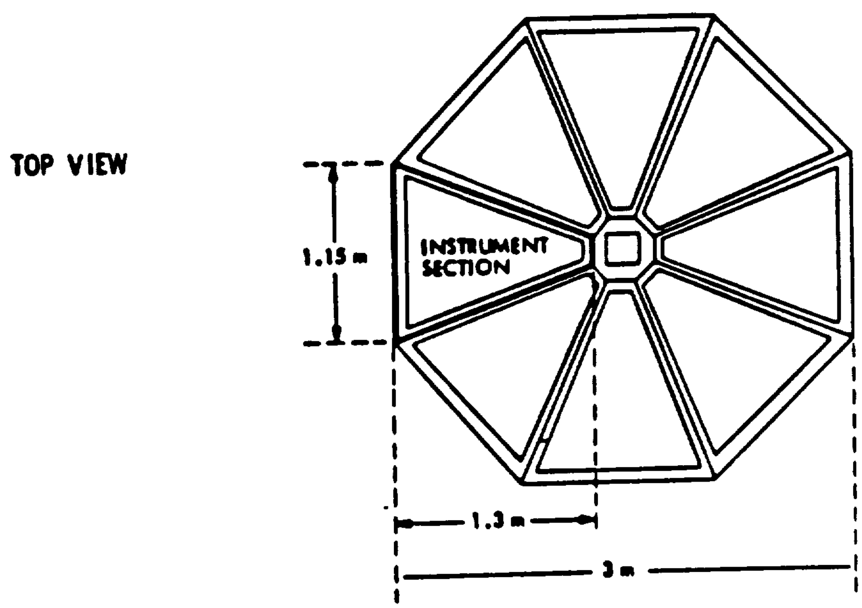


SECONDARY MIRROR CONTROL

ALIGNMENT SEQUENCE
Figure 2.4.5-2

2.4.5.3 <u>Align and Focus Scientific Instruments</u> - The Scientific Instruments are positioned radially around the 45° mirror which directs the telescope focal plane to the selected instrument (Figure 2.4.5-3). As the telescope is pointed at selected stellar features each instrument is positioned by micro-actuators to achieve optimum performance by aligning and focusing on the telescope image.

3. ALIGN AND FOCUS SCIENTIFIC INSTRUMENTS
- POINT AT SELECTED STELLAR FEATURES
- POSITION EACH INSTRUMENT, USING INCORPORATED MICRO-ACTUATORS UNTIL OPTIMUM INSTRUMENT PERFORMANCE IS ACHIEVED.



ALIGNMENT SEQUENCE
Figure 2.4.5-3

2.4.5.4 Align and Co-Boresight Fine Guidance Sensor - After the telescope and Scientific Instruments are fully aligned and focused the Fine Guidance Sensor must be aligned and co-boresighted with the telescope. This is achieved by a laser alignment reference device. Such a device is currently under development at the Eastman Kodak Company.

Crew and data rate requirements for the full alignment process are shown in Figures 2.4.5-4 and 2.4.5-5.

IVA - 2 PERSONS x 8 HOURS = 16 PERSON-HOURS

- VERIFY OPTIMUM PERFORMANCE OF SPACECRAFT SUBSYSTEMS
  - ATTITUDE CONTROL
  - POWER/SOLAR ARRAY DRIVE
  - COMMAND AND DATA HANDLING
  - PROPULSION
  - THERMAL CONTROL

IVA - 2 PERSONS x 20 HOURS = 40 PERSON-HOURS

- ALIGN AND TEST OBSERVATORY
  - PARABOLIZE PRIMARY MIRROR
  - ALIGN SECONDARY MIRROR TO PRIMARY MIRROR
  - ALIGN AND FOCUS SCIENTIFIC INSTRUMENTS

ALIGNMENT CREW
Figure 2.4.5-4

- FLYING IN CLOSE PROXIMITY TO SPACE STATION
- MODERATE DATA RATE FOR REAL-TIME "OBSERVATORY HEALTH" TELEMETRY APPROXIMATELY 50 KBPS
- COMPUTER ON-BOARD LDR FOR PROCESSING AND STORAGE OF SCIENTIFIC INSTRUMENT DATA
- SCIENTIFIC INSTRUMENT DATA DUMP RATE APPROXIMATELY 2 MBPS MAX. (TO GROUND)
- MODERATE COMMAND DATA RATE
- ABOUT 1 WEEK REQUIRED FOR OBSERVATORY STABILIZATION AND ALIGNMENT

ALIGNMENT DATA/COMMUNICATIONS
Figure 2.4.5-5

2.4.6 Transfer to Operational Orbit

The Space Station-based OMV will boost the LDR to its operating altitude, as shown in Figure 2.4.7-1, and then return to the station. At various planned intervals the OMV will rendezvous with the LDR for replenishment, replacement or TV inspection. On other unplanned occasions, the OMV may be employed for contingency reasons at the LDR. As shown in the figure, the LDR will have to reboost itself, or have the OMV reboost it to its operating orbit from the lower altitudes to which drag and gravity will force it.

Return to the station is only planned after long operational periods whereafter major repairs or changes are required.

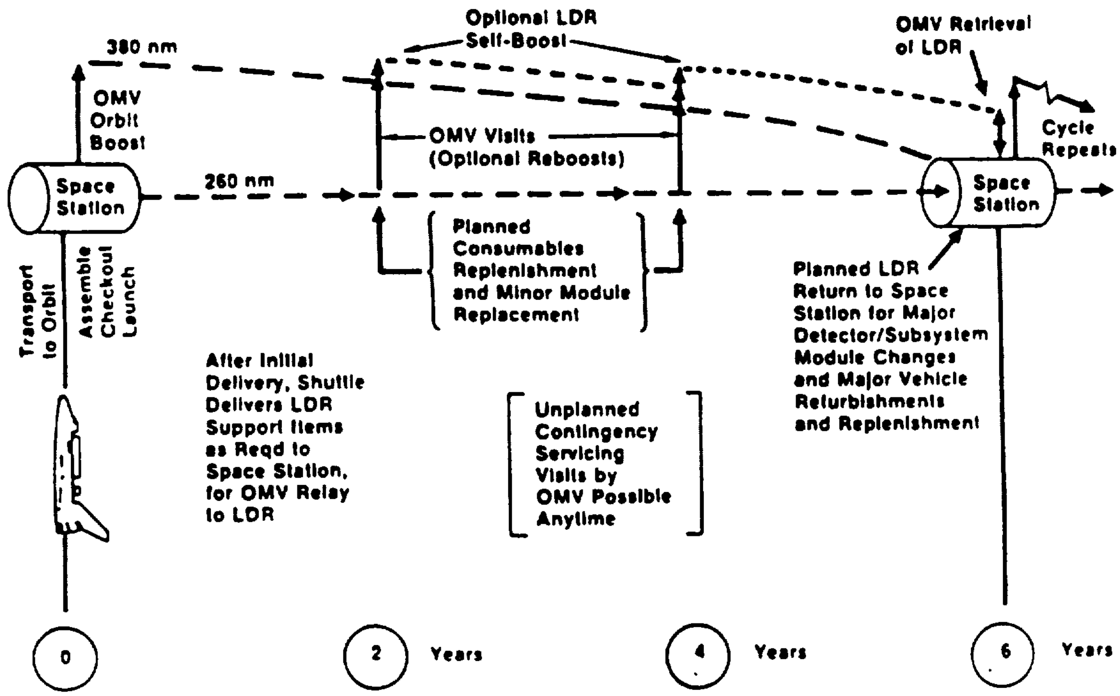
2.4.7 Resupply and Servicing

The types of services that will be provided remotely by the OMV, or on return to the station are listed in Figure 2.4.7-1. Note that instrument changes are envisioned primarily as coinciding with major advancements in instrument technology; which is assumed to be every five years. Therefore, the return of the LDR to the station every six years would seem to provide an opportunity for instrument exchange; a highly-complex interface activity which will benefit from many resources available at the station. Servicing needs are summarized in Figure 2.4.7-2.

Figure 2.4.7-3 is a collage of illustrations related to-the resupply and servicing operations. On the upper right side of the figure is shown an OMV delivering a servicing logistic module loaded with ORU's for replacing like items on the remotely-located LDR. Built into the logistics module is a highly flexible manipulator for exchanging the modules. This capability for remotely-controlled servicing is one of the many ways in which the Congressionally mandated emphasis on automation and robotics in the Space Station Program may be implemented.

On the lower left of the figure is an illustration of one concept for delivering the sizeable volumes of cryogenics which are seen to be necessary for the low-temperature operations of the LR instruments and the secondary mirror unit. Quite probably the OMV "tanker" will have to also dock on the secondary mirror unit end of the LDR for replenishment of its cryogenics.

The left side of the figure depicts the operations of unloading the ORU and cryogenic carrier modules and berthing them on the OMV prior to departure for LDR servicing.



ROLE OF SPACE STATION/OMV IN THE LDR LIFE CYCLE
Figure 2.4.7-1

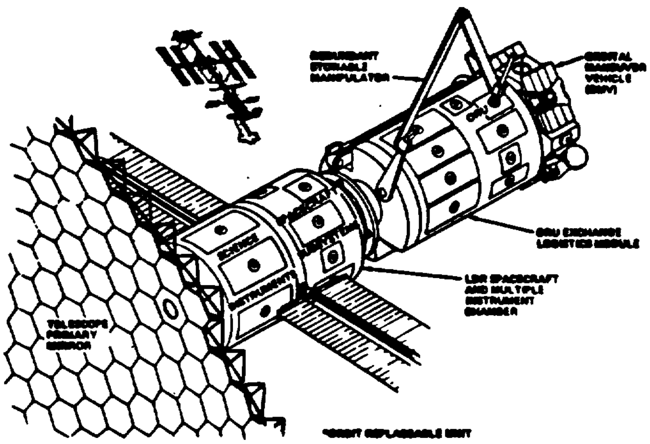
- Unplanned Contingencies
- Planned Maintenance
- Planned Replenishment
- Planned Exchanges

} • Payload • Spacecraft

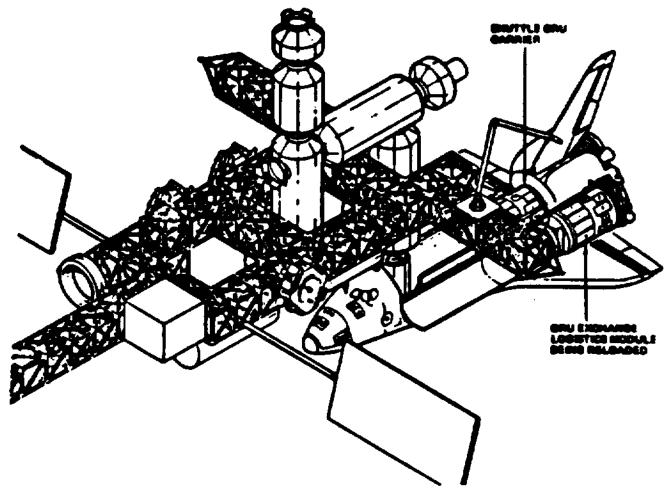
Item to be Serviced	Most Likely Type of Service and Location	Estimated Need (Aside from Contingency)
• Generic Instrument Resource Elements (Ambient) • Electr/Power Supp • Cryo Strg/Distrib • Mechan Coolers • Computers	ORU* Replacement Remotely (OMV/Servicer)	Every 2 1/2 Years (Modifications for Improvements or Performance Changes)
• Spacecraft Subsystems	ORU Replacement or Propellant Resupply (OMV/Servicer)	" "
• Ultra-Low Temp Instrument Pkgs (Incl Cryo Units)	Major Replacement at Space Station (Manipulator/EVA)	Every 5 Years (Capitalize on Major Technology Advances)
• Mirror Elements	" "	Every 5 Years (Damage/Degradation)
• Spacecraft	Major Refurbishment at Space Station (Ex:Radiators)	Every 5 Years (Wearout/Upgrade)

ON-ORBIT SERVICING OF LDR INSTRUMENTS, OPTICS AND SPACECRAFT
Figure 2.4.7-2

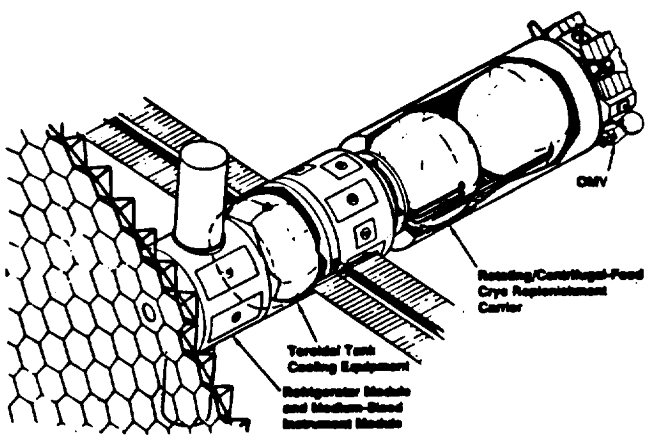
ORU* EXCHANGE LOGISTICS
MODEL (OMV-BASED)



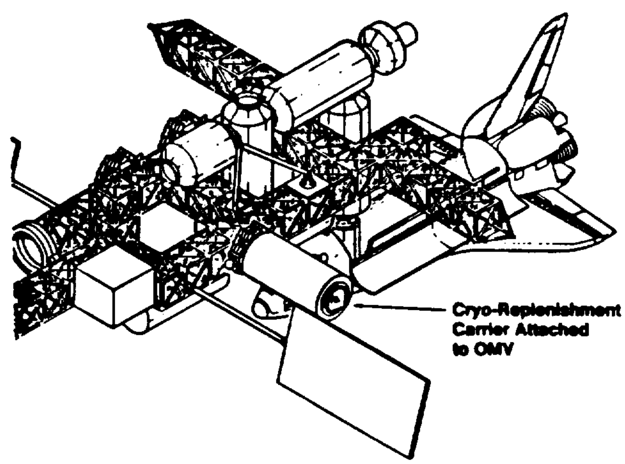
ORU EXCHANGE LOGISTICS MODULE
(RELOADING FROM SHUTTLE CARRIER)



LDR SERVICING/CRYO REPLENISHMENT



CRYO-REPLENISHMENT CARRIER LOADING



REMOTE SERVICING OF LDR
Figure 2.4.7-3

2.4.8 Re-configure/Refurbish

Re-configuration and refurbishment is planned at six (6) year intervals. Unplanned re-configuration or refurbishment may take place sooner if disabling failures occur or an urgent need arises to replace an instrument. Due to the extent of operations and the need for spares it will be necessary to return LDR to the Space Station for re-configuration or refurbishment. The OMV/OTV will travel to LDR's operational orbit, attach to LDR and return it to the Space Station.

Selected small spares will have been brought to the station from time to time, when convenient, and stored. Larger spares and those having special storage requirements will be brought to the station closer to the time of need. Spare parts requirements and STS manifesting plans will be defined during LDR development.

When LDR is returned to the Space Station it will be mounted in the yoke and contamination shields used earlier for assembly and checkout. Power, data communications and thermal requirements will be similar to those during the final stages of post assembly checkout. Crew requirements will vary according to the number of anomalies and replacements/repairs needed. Typical expected crew requirements are shown below.

1 Week - Re-configure/Refurbish - 80 Person - Hours
2 Weeks - Checkout - 250 Person - Hours
1 Week - Realignment - 60 Person - Hours

3.0 REQUIREMENTS ON SPACE STATION

3.1 PLACEMENT

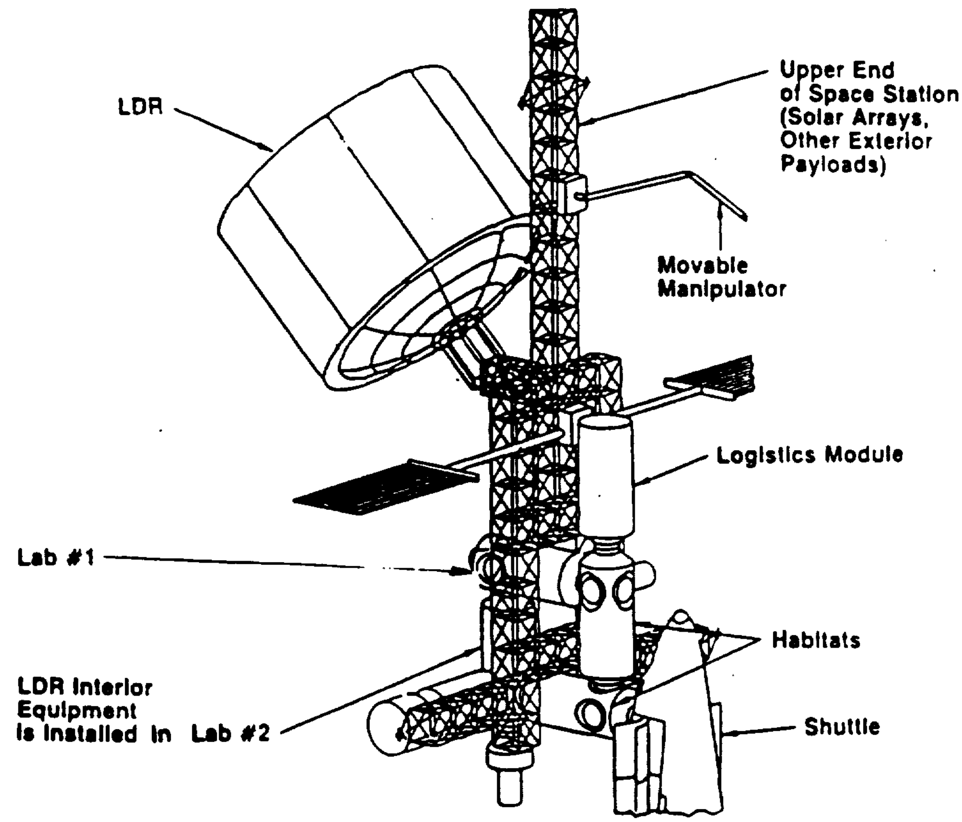
LDR equipment will be placed and accommodated at several locations on the Space Station. On the station exterior, the LDR vehicle will be constructed on what is termed the Large Mission Assembly and Test Site (LMATS) which is on the trailing side of the mid-keel (chosen to minimize C.G. impacts of large added loads), as shown in Figure 3.1-1. Cargo loads delivered by the Shuttle will be stowed temporarily during construction along the mid-keel side to permit MRMS access and yet passage along the keel. The LMATS also permits direct, straight-line separation (launch) from the Space Station as well as reberthing without interference with other user or station functions. Cryogenic fill or replenishment tanks for user support will most likely be located near LMATS as will other refueling tank forms. Just above the LMATS and along the side of the mid-keel (not shown) will be a large locker for the temporary stowage of instruments or other replaceable items that are awaiting installation in spacecraft that are serviced on the station.

As discussed earlier, in 2.4.2 - Handling and Storage, the LDR control, monitoring and diagnosis consoles will be mounted inside one of the core LAB modules of the station, most probably #2, as shown in the figure. In this module also is equipment for other spacecraft being serviced, or sensors that are mounted and operated on the Space Station upper or lower booms. Actually, LDR will be on the station in what is termed the "Growth era", wherein additional LAB modules will have been added to supplement LABS 1 and 2.

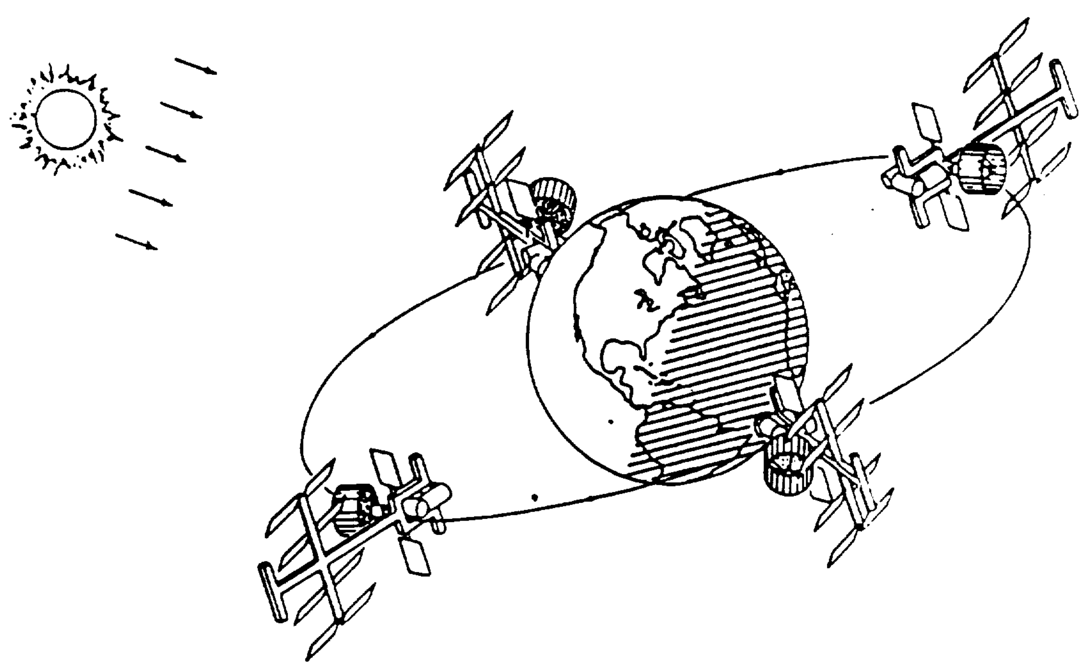
Figure 3.1-2 illustrates the relationships of the LDR position on the Space Station as it orbits the Earth and indicates further substantiation of the need to provide a "lens cover" to preclude solar radiation impinging on the LDR optical system, in addition to general contamination avoidance.

The accessibility of various utility resources to an LDR activity mounted at the LMATS location is illustrated in Figure 3.1-3. The currently-defined locations for junction for (users) on the main power, thermal and data/communications are shown. Special umbilicals will be required to extend these resources to wherever the LDR berthing interface may be, i.e., through a berthing mechanism on the end of the LDR spacecraft, or side entry plugs on the spacecraft. Capacities and sizes are also indicated. Figure 3.1-4 illustrates how the LDR payload equipment would interface with the data/communications subsystems of the Space Station along with a listing of available services.

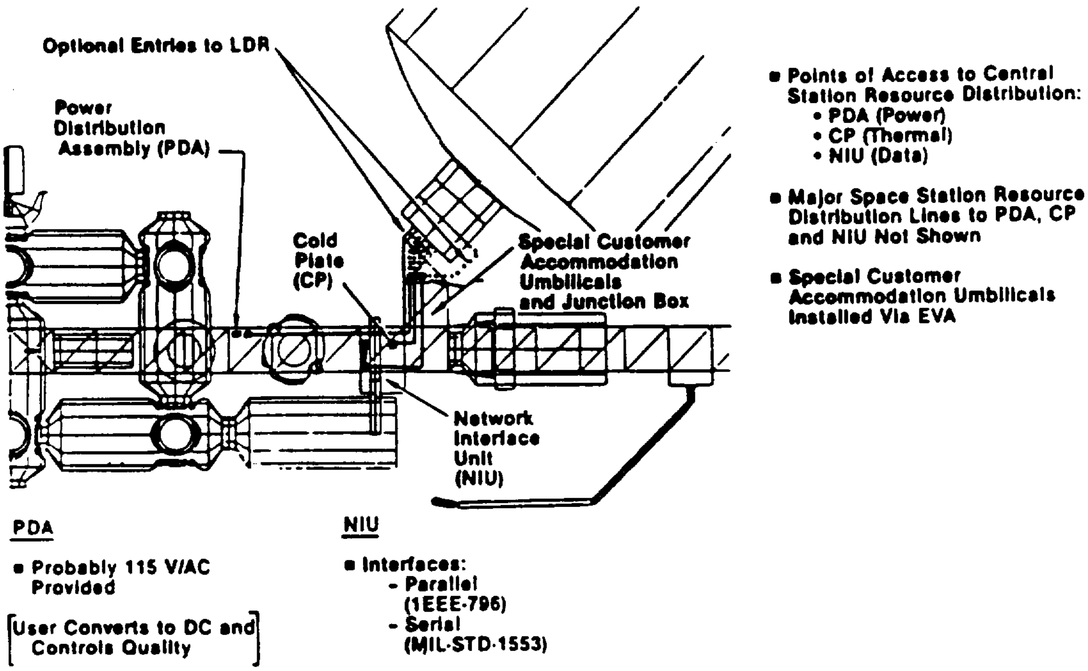
Near the completion of this study, the NASA Space Station Program Office selected a new "Dual-Keel" configuration, as opposed to the original baseline "Power Tower". Most of the LDR/station interface conclusions of this study (using Power Tower) still apply to the new configuration. The assembly site for the Dual-Keel configuration is shown in Figure 3.1-5 on the aft/left keel.



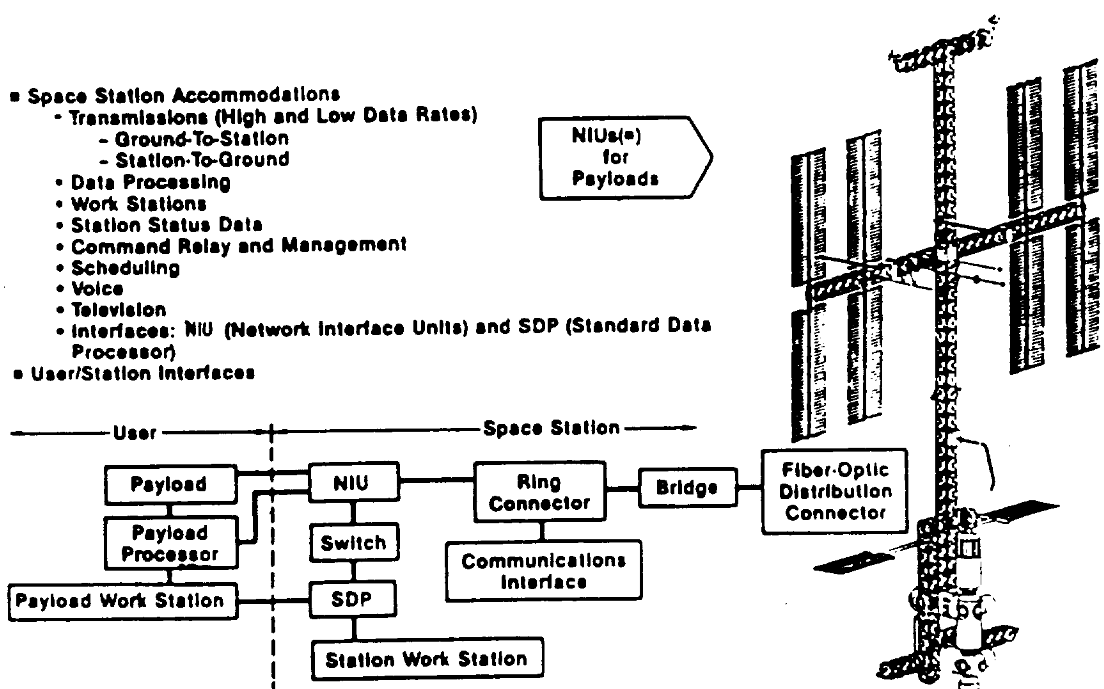
LDR/SPACE STATION CONFIGURATION
Figure 3.1-1



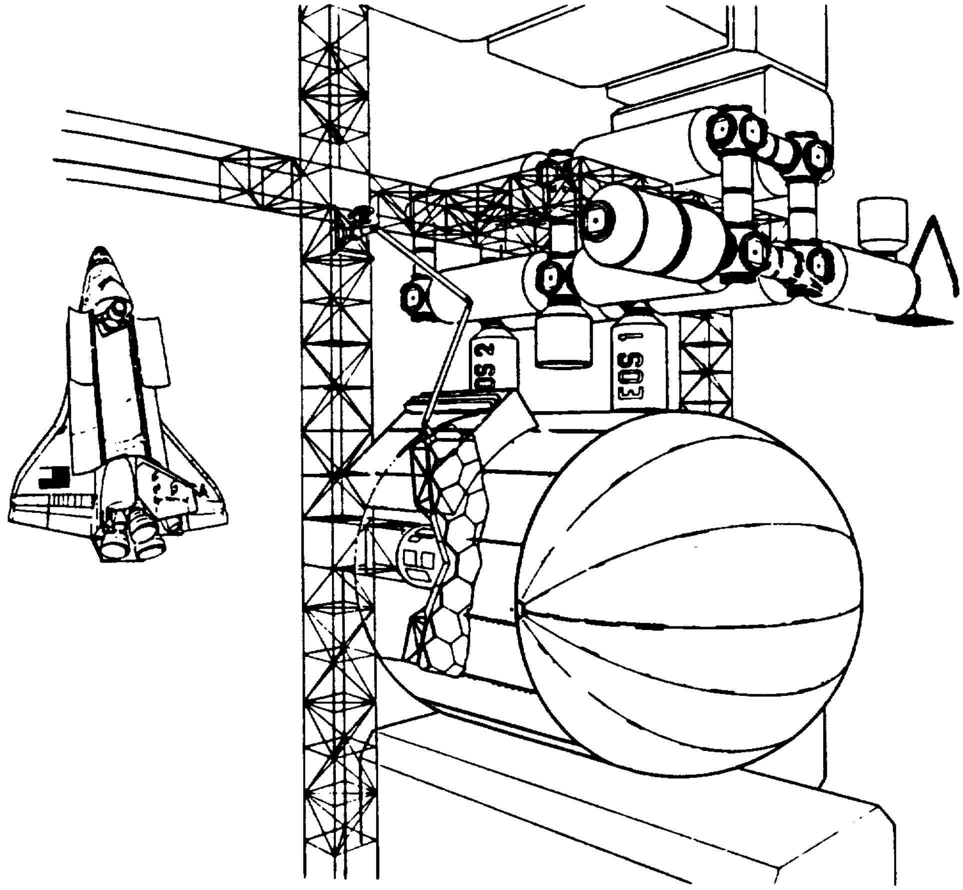
LDR AND SPACE STATION ORIENTATION
Figure 3.1-2



UMBILICAL ACCESS TO STATION RESOURCES
Figure 3.1-3



USER DATA AND COMMUNICATIONS
Figure 3.1-4



LDR ON GROWTH STATION
Figure 3.1-5

3.2 INTERIOR AND EXTERIOR SPACE

Interior space will be required in the Logistics Module for transportation and storage of test equipment required during assembly, check-out and alignment of LDR. The equipment will be moved into the Habitat Module prior to LDR assembly and back into the Logistics Module after LDR becomes operational until needed again for reconfiguration and refurbishment of LDR. At present this space need for the LDR work station and associated equipment is projected as two to three full racks of equipment, or equivalent. Figure 2.4.2.2-3 shows LDR Interior Equipment Delivery Logistics, and Figure 2.4.2.2-4 shows the LDR Internal Control Center.

Exterior space required for the fully assembled LDR with Scientific Instruments, Spacecraft, Contamination Avoidance Skirt and "Lens-Cover" is expected to require a space about 35 meters in diameter by 40 meters long. The total volume will be about 38,500 cubic meters.

3.3 DYNAMIC REQUIREMENTS

The LDR/station interactions involving dynamics is a two-way street, i.e., what the station (and other users) will impose on the LDR and vice versa.

During construction of LDR the imposition will be mostly from LDR to others, that is, the dynamics of MRMS manipulations and transit movements with large size items could impose unwanted dynamics on the MICRO-G processing users inside of the laboratories. However, it is currently believed that dynamics-diminishing design of the MRMS and constrained operating procedures (scheduling, duration, directionality, etc.) will decrease such impositions on other users to an acceptable level.

Conversely, when the LDR construction is at the stage where check-out of optical systems is needed, there will be a need to call for a maximum attempt at quiescence on the station, by both station and other user functions. This is not seen to be a major problem since the duration of such LDR optical tests will not be long. However, final optical systems tests require that the LDR by separated from the station. After such tests are complete, the LDR may be returned to the station for final adjustments and/or consumable replenishment, if necessary.

Currently, there are concepts being considered for the isolation of station dynamics from high accuracy pointing instruments which are intended to operate for long periods attached to the station. Such isolation equipment will be mounted on the Coarse Pointing System (CPS) which is planned for installation at possibly a dozen different locations on the Space Station upper and lower booms, for stellar and Earth-oriented instruments.

Consequently, it may be feasible for LDR to conduct more extensive optical performance tests through the use of a CPS which incorporates some type of isolation capability.

The impact of the heavy LDR on the Space Station control system was analyzed and the results are indicated in Figures 3.3-1 and 3.3-2. Since the LDR is still in concept status, a range of weights from 20-65,000 Kg was used. In comparison with the periodic docking of the Shuttle vehicle, the LDR will not create any unusual challenges for the control capability to (1) maintain an acceptable altitude envelope or (2) manage the resultant momentum profiles. The anlayses were run for two locations on the keel, i.e., 49 and 52 meters down from the center of mass.

Approach

- Assumed 20,000 to 65,000-kg LDR mass located near Space Station CG with and without orbiter

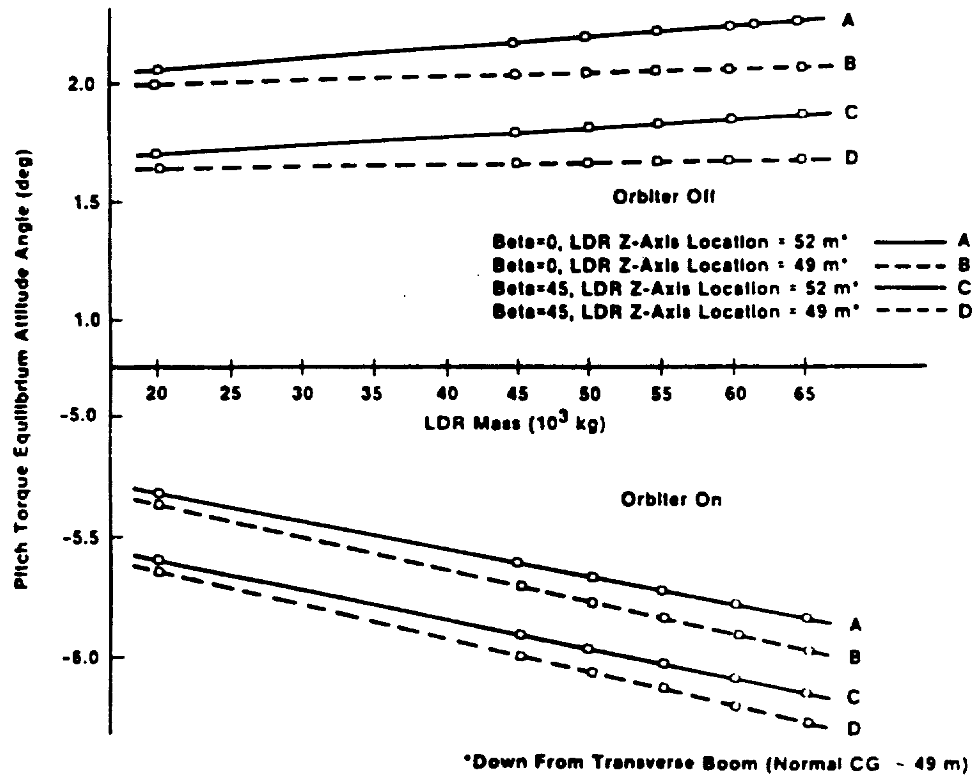
Results

- LDR-induced variations in Space Station flight attitude are acceptable
- Momentum storage requirements not significantly impacted by LDR located near Space Station CG
- Construction-induced disturbances expected to be similar to other operations using crew and MRMS

Comment

- CG of Space Station is a good place for large payload construction (low impact on micro-g users and station attitude control system)

SPACE STATION CONTROL IMPACTS OF LDR
Figure 3.3-1



SPACE STATION PITCH ATTITUDE OFFSET
VERSUS LDR MASS AND LOCATION
Figure 3.3-2

3.4 THERMAL REQUIREMENTS

LDR when fully assembled, including SI's, will require about 3,525 watts to maintain thermal control of the telescope and cool the Scientific Instruments. Heat rejection will require about 19 square meters of radiator area at 300°K. No special pointing orientation requirements are currently envisioned.

3.5 IVA/EVA REQUIREMENTS

The role of the LDR/Space Station crew is outlined in Figure 3.5-1. After considerable involvement in the development/production program, LDR-assigned crew members will be delivered with the LDR cargo via the Shuttle. The initial IVA tasks involve the control of unloading exterior LDR equipment carriers from the Shuttle and berthing them on or near the large mission assembly and test site. Also, the LDR operations monitoring/control and system diagnostic consoles must be removed from either the regular Station Logistics Module or some separate, pressurized User Logistics Module (both delivered by the Shuttle and attached at some berthing port of the LAB or HAB modules) and then transferred via IVA to their pre-assigned point of installation inside one of the Lab modules. Here, the crew will install and secure the console in a rock-like location and hook up any cables or ducting or cold plate attachments.

- Support of Design Activity and Operations Planning (Incl I/F With Shuttle, Space Station and OMV)
- Training With Simulators, Prototypes, Etc.
- Pre-Flight Coordination With Mission Controllers
- Transport to Orbit With LDR Equipment
- On-Station Orientation and Coordination
- LDR Equip. Unloaded, Stowed, Berthed on Station
  (Interior Equipment Checked Out)
  (Exterior Equipment Inventoried)
- Deployment/Assembly/Alignment
  - Primarily Robotic (IVA Activation/Monitoring, Plus EVA Monitoring, Final Attchmts and Selective Structural Element Emplacement, and Contingency Aid/Repair)
- IVA Coordination With Ground Controllers and Advisors, Space Station Core Crew, Data Analysis, Situation Diagnosis, Procedural Adoption and Log-Keeping
- Overall LDR Calibration and Checkout Prior to Separation From Space Station

ROLE OF LDR/SPACE STATION CREW
Figure 3.5-1

For the construction of the LDR, the station Mobile Remote Manipulator, EVA and a special intra-LDR manipulator will be used in varying combinations. Special crew training will be required on Earth for the LDR-EVA activities including considerable underwater simulations (similar to those performed already for LDR under MDAC-IRAD) to assure efficiency as well as contingency-response effectiveness.

For the initial construction task the LDR self-enclosure, i.e., Sunshield, "Lens-Cover" and Aft Thermal Shield, the EVA procedure will involve the removal of various structural and blanket items from the end-effector of the MRMS (which will have extracted them from the cargo carrier berthed near the site) and assemble them as per instructions relayed by voice and a special mini-TV image integrated within their helmets.

This phase of the operation will also involve the assembly and installation of the temporary access port on the side of the LDR (mentioned previously in 2.4.2).

Numerous special EVA tools will be required as will, quite probably, some portable EVA work stations (that can be attached at various work sites). Although by the LDR time period the complement of Space Station general purpose tools will satisfy many of the LDR construction requirements, some additional aids and tools will be required, for example, large thermal blanket deployment and attachment aids.

Once the LDR "self-enclosure" is completely assembled and checked for cleanliness, the remaining construction will involve the extraction of environmentally-sensitive LDR parts from their cargo container which is attached to the access port and opened via EVA on the inside to permit part removal. The EVA life support system used here requires vent containment.

At this point in the activity, the special intra-LDR manipulator (which is installed and used only for construction) will be used to extract parts from the cargo carrier and move them to their assembly site. Although the operation will be heavily automated, extensive EVA will be used for the final attachment and securing functions.

The sequence of internal construction was outlined earlier in 2.4.3, Assembly.

At the completion of construction, and removal of the airlock and LDR internal manipulator, the IVA-performed checkout operation begins. Next, the IVA crew would conduct a pre-launch countdown and arrange for attachment of the OMV to the end of the LDR for off-site transport. OMV attachment to payloads and spacecraft will have been performed many times previously using the MRMS, so no EVA is envisioned for the function in the LDR time period.

Next, the IVA crew would, in conjunction with ground-based specialists at mission control, operate the LDR via remote control in its co-orbit flight to test its performance. A considerable amount of IVA data analysis and re-testing is anticipated for the off-site testing as well as the on-site testing.

On successful completion of the off-site testing, the IVA crew, in concert with the Space Station crew, may direct the return of LDR/OMV combination to a point where capture by the MRMS and subsequent berthing/OMV unberthing is possible. At this point, there is a possibility that some EVA corrective action or item replacement would be required. This might require access to the LDR interior optical and instrument regions. This would require a new vent-containment accessory, in addition to the standard EVA equipment, unless some other contaminant sensitive construction creates an earlier need for such an accessory.

After perhaps 6 years of operation, when the LDR is returned to the station, there will most likely be a requirement for EVA to refurbish or replace thermal control surface blankets, subsystem and instrument modules or units and, conceivably, even some mirror panels, all of course under IVA crew direction and maintaining in coordination with expertise on the ground.

3.6 TELEOPERATOR/ROBOTICS REQUIREMENTS

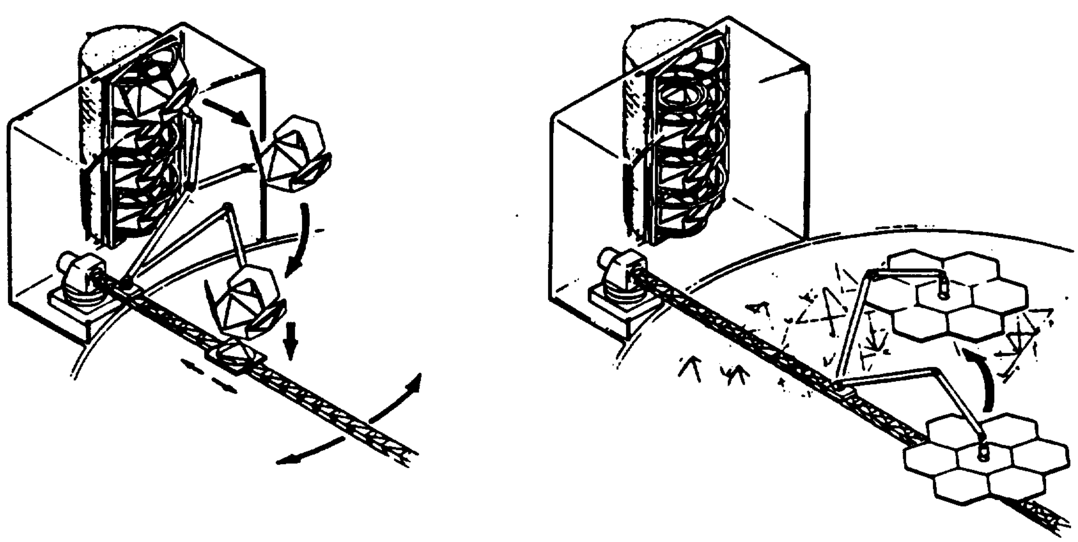
Major use of the Space Station MRMS (Mobile Remote Manipulator System) will be made for LDR cargo transfer and construction. However, an internal manipulator is also needed to safely and efficiently transfer and install all of the major internal LDR components. Such automatically controlled manipulation is needed to reduce the requirement for EVA time, critical because of the need for a backup EVA crew person and an IVA minitor, all essentially dedicated to one payload (mission) activity.

Overall crew time will always be at a premium on the Space Station, and EVA makes a significant demand on the crew team. Beyond that factor, the LDR components are made of very high accuracy hardware and are, in some cases, unwieldy in size and shape and sometimes very fragile. As a result, a special manipulator with various end-effectors will play a major role in the construction of LDR. Earlier, in this report, Figure 2.4.3-3 illustrated the geometry and function of this manipulator (see also Figure 3.6-1).

It's function is to extract various components out of their cargo delivery container, where they are stowed in closely-nested arrangements. This part of its function could be pre-programmed extensively since the exact coordinates of each item in the container will be known. EVA functional support will still be necessary to unfasten or unlatch components in their restraints in the container.

Next, the manipulator will transfer the components to their installation positions, also known exactly from LDR drawings. There, EVA support will provide manipulator release control and take over for final attachment in-place.

The reach of the internal manipulator must extend not only across the 20 meter face of the LDR but also up at various angles to locations as far away as the opposing side of the sunshield and the secondary mirror unit. Consequently, it will have a "shoulder," "elbow" and "wrist" capability and perhaps an extension capability of up to 30 meters, probably through some telescopic arrangement.



LDR MIRROR ASSEMBLY MANIPULATION
(INSIDE AIRLOCK AND LDR SUNSHADE/TOP)
Figure 3.6-1

Although complex, this manipulator will require no more technology than exists today, since there are many cargo handling manipulators in existence. There is also a distinct possibility that it may be used to support servicing functions elsewhere on the station to relieve an anticipated heavy MRMS workload.

3.7 STORAGE REQUIREMENTS

A variety of storage will be required for LDR on the Space Station, since LDR components will be brought to the station and assembled over a many-month-period, and LDR Shuttle cargo loads may be optimally "stuffed" with some equipment that is not immediately for construction on arrival.

The storage of initially delivered LDR items will be in their Shuttle cargo container which will be parked near the Large Mission Assembly and Test Site (LMATS). Therefore, LDR requires (for possibily 45-60 days after initial load delivery) a 50 foot long parking space on either side of the keel adjacent to LMATS.

The subsequent launches (2,3,4) involve environmentally closed containers which are attached directly to the side of the LDR sunshield, and therefore LDR provides its own parking, or storage space. The fifth and last load brings up the instruments and spacecraft which are removed from the Shuttle and attached immediately to the bottom of the LDR. There is a possibility of some interim parking requirement here if the LDR activity is not quite ready for the newly arrived equipment; possibly two weeks of near-LMATS parking space of up to 50 feet long. The delivered equipment could be mounted side-saddle to the keel with special Shuttle-replication sill-trunnions and an extendable keel fitting.

Cryogen-topping of LDR before separation from Space Station will require storage of several cryogen tank/loading units for two-or-three different cryogens of the prepared multi-temperature layer cooling jacket concept. Liquid hydrogen would be available on station from the OTV activity, but a mobile transfer unit would be required even for that since cryogen will in all probability not be plumbed to the LMATS region. Thus, there will be 2-3 cryogen storage/loading units that require packing most likely near the LMATS site. Conceivably they could be taken out of the Shuttle (which delivers them) moved to LDR on LMATS, load cryogens into LDR, and be returned to the Shuttle for ground return; thus eliminating the need for parking, if such an idealized schedule is feasible.

After the LDR is in its solo-flight operational mode, periodic servicing from Space Station will require the storage of ORU's for equipment and, perhaps, propellants. The equipment would require external storage, probably again along the keel somewhere out of the path of MRMS (manipulator) movement. The equipment-type ORU's would consist of up to six units of 2x4x6 feet each and the propellant ORU would probably be about the same. These units would be mounted in some sort of an ORU carrier on the front of the OMV/SMARTKIT for transport to, and loading of, the distant LDR.

3.8 CONTAMINATION/ENVIRONMENT REQUIREMENTS

The protection of LDR from contaminating environments begins with the use of special enclosed Shuttle cargo containers, which are being proposed for general use by many Space Station payloads. After arrival at Space Station a variety of other potential sources of contamination must be countered with protective measures (see Figure 3.8-1). These, in great part, tie to the decision for LDR to enclose itself completely using the Sunshield plus a "convertible top" Lens-Cover.

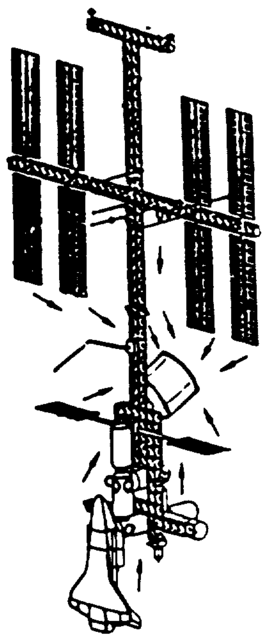
The particular environment surrounding the LMATS area where LDR will be constructed is shown on Figure 3.8-2. Here, a variety of thermal radiation prospects (severe in the case of solar-dynamic power concentrator gimbal failure) are envisioned. This may dictate an increase in performance of the thermal shield of the LDR over and above that of natural thermal radiation requirements.

Figure 3.8-3 lists an overall spectrum of environments that may be imposed on LDR while on the Space Station, not only by the station but by other users as well.

OPERATING REGIMES OF CONCERN

- Delivery to Orbit in Shuttle Cargo Bay
- Loading/Deployment/Assembly/Checkout on Space Station
- Rendezvous With Shuttle
- Rendezvous With OMV for Resupply/Refurbishment
- Rendezvous With Space Station
- Unusual Micrometeorites, Debris, or Radiation
- Contingency Situations (Thermal, Maintenance, Storage)

ENVIRONMENT PROTECTION FOR LDR
Figure 3.8-1



Thermal Radiation

- Module Cluster
- Radiators
- Solar Panels
- Solar Concentrators
- Nearby Cargo

Thermal Conduction

- Berthing Mechanism
- Umbilicals

Contamination

- Attitude Control Propulsion
  - Probably Hydrazine at Mid-Keel (Ammonia Products)
- Spacecraft Servicing
  - Various Fluid Leakage
- Manned-Modules
  - Atmospheric Leakage
- Shuttle
  - Cabin Leakage
  - Wet Trash Vent
  - Human Waste Water

ENVIRONMENTAL IMPOSITIONS ON
LARGE MISSION ASSEMBLY/TEST SITE
Figure 3.8-2

The contaminants of the Shuttle RCS engines are discharged towards the Space Station during rendezvous maneuvers. Figures 3.8-4 shows the severity of the depositions calculated for regions near the LDR, based on MDAC computer code analysis. This situation could happen with possibly 6 to 8 Shuttle rendezvous during the LDR residence on station.

Figure 3.8-5 illustrates and quantifies the severe thermal loads which could be created by an off-axis sun condition (failed gimbal) on the solar-dynamic power concentrator dishes. The Space Station is taking steps to preclude such an imposition, but there may be momentary high-loads before a failed concentrator dish gimbal condition is resolved.

System-Generated

- Contamination
  - Shuttle rendezvous, Cabin Leakage, Human Waste Water, Wet Trash Vent
  - Station reboost (orbit keeping)
  - OTV/OMV docking and servicing — propellant transfer, material outgassing, abrasion/wear, etc from EVA suits, OMV tools, and MRMS
  - Material outgassing
  - EVA operations
  - Pressurized module leakage
- Dynamic Disturbances
  - Orbiter docking
  - Crew motions, kickoff, sneezes, maintenance operations, etc.
  - OTV flights
  - OMV flights
  - Station EVA activities
  - Orbit keeping
  - MRMS movement/operations
  - Payload installation/removal
- Operational Interruptions
  - Orbiter arrival/departure
  - OTV and OMV flights
  - Orbit keeping
  - Payload installation/removal
  - Major servicing/construction
- Thermal Loads
  - Radiator heat rejection
  - Off-axis illumination via solar concentrators

Payload-Generated

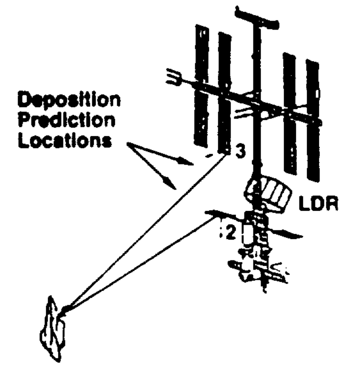
- Electromagnetic interference
- Tether dynamics
- Life science centrifuge
- Structure test dynamics
- Venting
- Slewing
- Thermal
- Large element assembly
- Spacecraft refueling and servicing

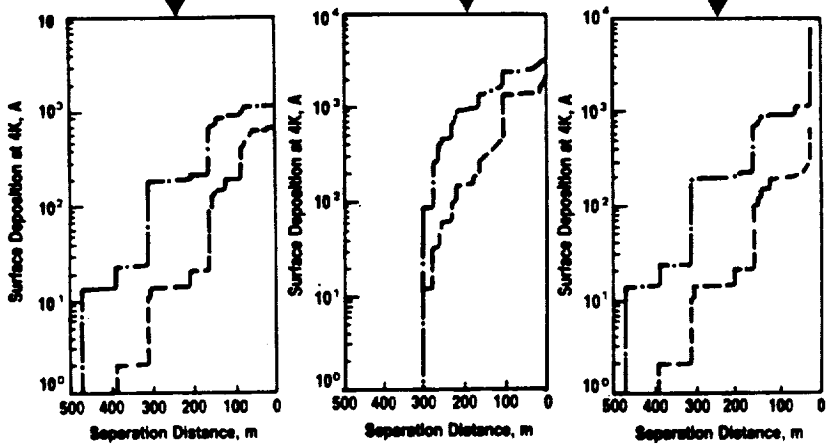
INDUCED ENVIRONMENTS ON SPACE STATION
Figure 3.8-3

- **Rendezvous With Shuttle**

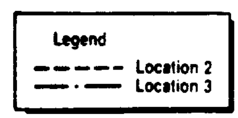
PRCS Plume Induced Space Station Contamination Predictions

Space Station Location	Allowable Deposition (A/Yr)		Predicted Deposition (A)					
			Normal-Z Approach		90° Yaw		Low-Z Approach	
	At 4K	At 298K	At 4K	At 298K	At 4K	At 298K	At 4K	At 298K
2	40	100	668	7	2865	29	622	6
3	40	100	1104	11	3187	32	7505	75





- Worst Cases
- Primary RCS Engines Only
  [Vernier RCS Engines to Be Used Extensively to Reduce Contaminants]
- LDR Enclosure Warranted for STS and Other Contaminants



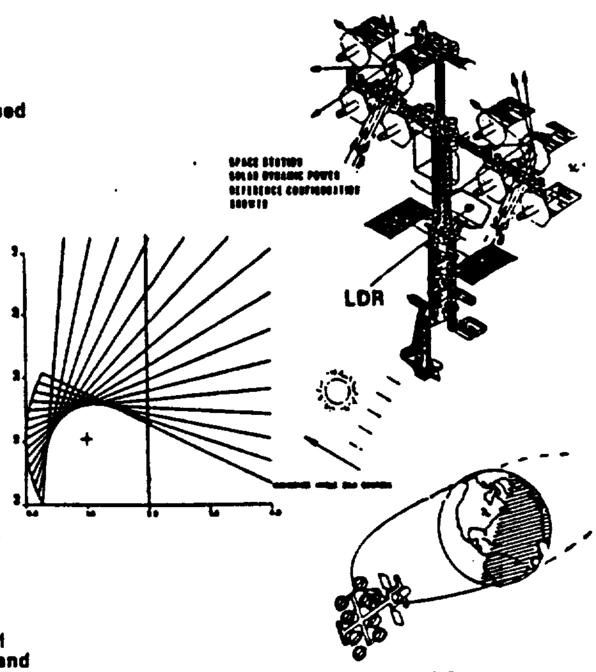
LDR CONTAMINATION
Figure 3.8-4

Interface Problem

- During LDR Assembly and Checkout, Unusual Thermal Loads could be Imposed on LDR by Station Power System
- Normal Operating Modes Causing Problem:
  - Off-Pointing to Prevent Thermal Storage Overloads or Shutdown/Restart
  - Ocean, Moon, Stars, Lighting Reflections
- Failure Modes Causing Problem:
  - Alpha Gimbal Failures (Coarse or Fine)
  - Beta Gimbal Failures (Coarse or Fine)
  - Station Yaw Control
- Peak Flux Density (Suns)/Degrees Off Track:
  20,000/0°, 1140/15°, 860/30° and 190/50°

Candidate Solutions

- Temporary Reflective Barrier Wall
- Compensate for Additional Thermal Load in LDR Sunshield, Radiators and Cyro Instrument Module Design



LDR and Concentrators Facing Sun

OFF-AXIS ILLUMINATION IMPACTS
(SOLAR CONCENTRATORS TO LDR)
Figure 3.8-5

3.9 SCARRING

The term "Scarring" is used to describe an accommodation change to the Station which has a large impact on the Space Station configuration and which precipitates a major redesign or modification of the Station. An example might be a need to add or delete a major load bearing member of the basic Space Station design.

The LDR concept as currently envisioned contains no elements which would cause scarring of the Space Station "Power Tower" configuration as described in the "Space Station Reference Configuration Description", dated August 1984.

4.0 AUXILIARY DATA

4.1 NUMBER OF STS FLIGHTS

As indicated in Section 2.4.1, it is expected that LDR transportation to the station may take as many as five flights. An example flight manifest is shown in Figure 2.4.1-1. The cumulative impact of LDR mass on the Space Station by flight, is shown in Figure 4.1-1, for that example.

It is assumed that these five LDR mission dedicated flights will occur over a 9 to 12 month time span. This is, however, an ambitious assumption based on current plans of 4 flights per year for basic LDR needs and 5 payload oriented flights per year. Other mission launch requirements and Space Station logistics may tend to restrict the number of launches available for any single mission such as LDR. Further optimization of flight manifesting might possibly reduce the number of flights.

4.2 POINTING AND ORIENTATION

Pointing and orientation requirements are not anticipated to be critical, while on the Space Station. The lens cover will be designed to protect the telescope from direct sunlight and earth glow during assembly. The telescope orientation will be established primarily to facilitate assembly. Critical alignment and focus operations, requiring precise pointing and anti-solar/ anti-earth algorithms, will not take place until the telescope is removed from the station and placed under its own attitude control.

4.3 POWER

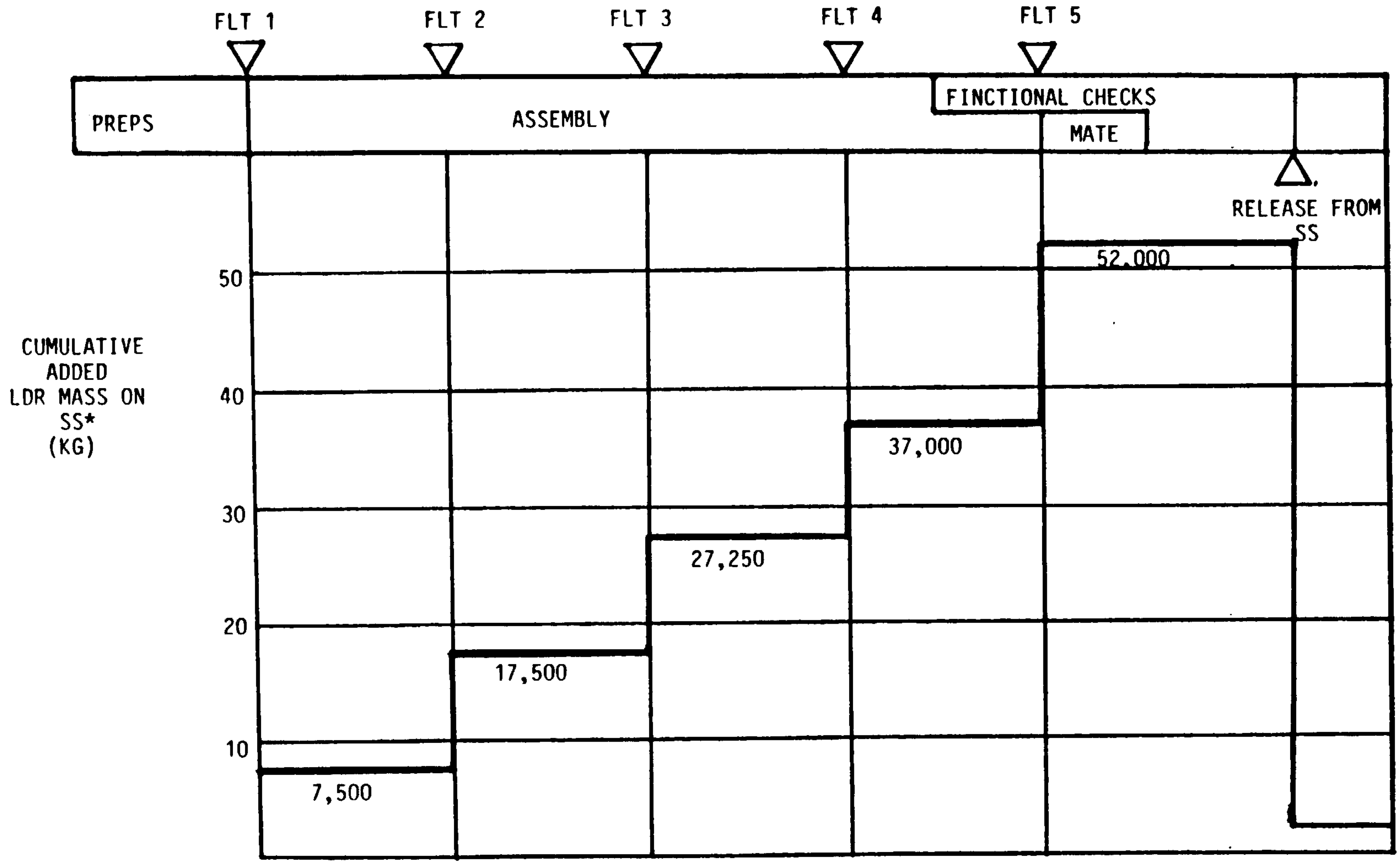
LDR payload unique power requirements, in addition to normal station functions, are summarized below by mission phase.

Mission Phase	Payload Unique Power Requirements (Watts)
Transportation	Nominal
Storage	Nominal
Assembly	Nominal
Check-out	4,100
Alignment	Nominal
Transfer	Nominal
Re-Supply	Nominal
Re-configuration/ Refurbishment	4,100

These values do not include power needed for Space Station functions such as MRMS, Communications, EVA, etc.

4.4 DATA AND COMMUNICATIONS

LDR payload unique data and communication requirements, in addition to normal station functions are summarized below, by mission phase.



*EXCLUDES: YOKE, SKIRT, CABLING, PROPELLANT FOR LDR INTEGRAL S/C, MISSION SPECIALISTS SUPPORT

LDR TRANSPORTATION IMPACT ON SPACE STATION MASS

(BASED ON EXAMPLE FLIGHT MANIFEST)

Figure 4.1-1

Mission Phase	Payload Unique Data and Communications (KBPS)
Transportation	Nominal
Storage and Handling	Nominal
Assembly	Nominal
Check-out	159
Alignment	50
Transfer to Operational Orbit	Nominal
Re-supply	Nominal
Re-configuration/ Refurbishment	159

While on the Space Station, LDR data outputs will be connected to station the Network Interface Unit (NIU) and Standard Data Processor (SDP). Parallel data will be formatted in accordance with IEEE-796 and serial data in accordance with MIL-STD-1553. Monitoring and control will take place in the Lab Module.

4.5 THERMAL COOLING

Active thermal cooling will be required to maintain the Scientific Instruments at or near their operating temperatures, which may be as low as 2°K. Present plans are to mount a hybrid cooling system adjacent to the Scientific Instruments. Coolants will be liquid nitrogen (77°K), liquid hydrogen (20°K), liquid helium (4°K) and superfluid liquid helium (2°K). These instruments and the cooling system will be brought (in a cooled state) on the last Shuttle flight and will be among the last items installed on the observatory. Because of the very low temperatures, extreme care will need to be taken to avoid contamination.

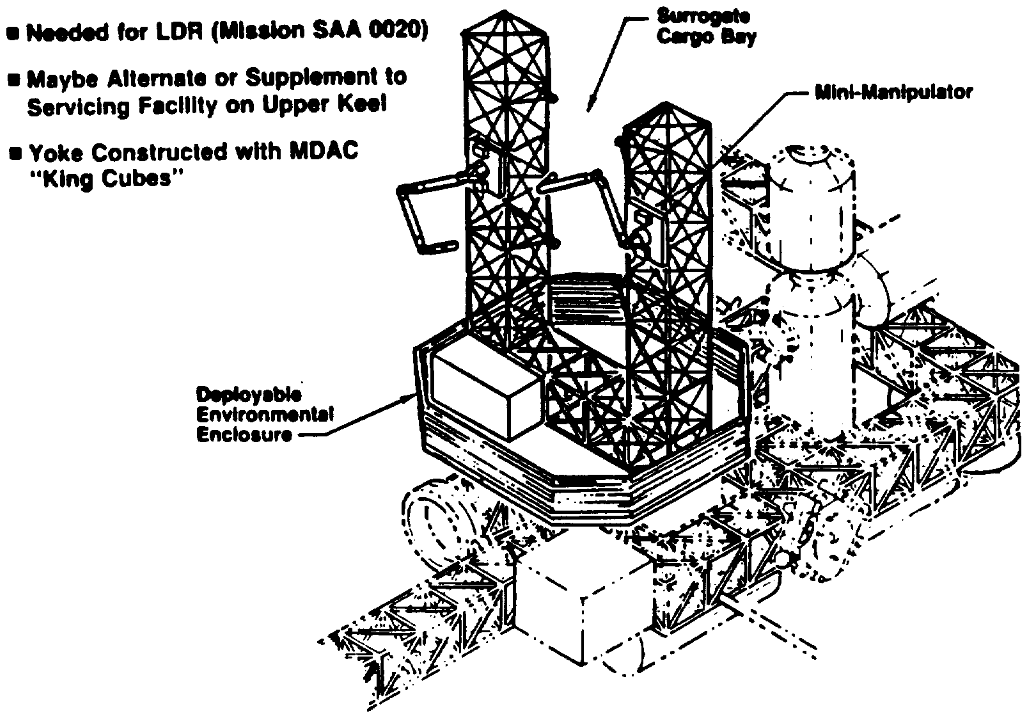
The Secondary Mirror must also be cooled to maintain it at 125°K. It may use coolants from the SI's hybrid cooling system plumbed to the mirror location or it may use stored cyrogens at the mirror location.

The Primary Mirror will be cooled semi-passively and heated to its operating temperature by trim heaters to meet the temperature uniformity requirements.

4.6 SPECIAL EQUIPMENT (OPTION)

For a number of reasons, one optional approach to mounting LDR on a Space Station involves the use of a structural yoke, as shown in Figure 4.6-1. First of all, it would be convenient to hold the LDR spacecraft by the same trunnions used to stow it in the Shuttle cargo bay. In the enclosed spacecraft servicing bay on the upper part of the spare station, spacecraft will be held in just such a manner. In fact, in view of the heavy load of spacecraft servicing on the station, and the unanticipated delays of potential contingencies in servicing, a second servicing type berth could be required.

The yoke would be built-up of deployable truss-work cubes, the same size as one module of the station keel or booms. These cubes are stored in quantity on the station for use in meeting special payload mounting or separation requirements.



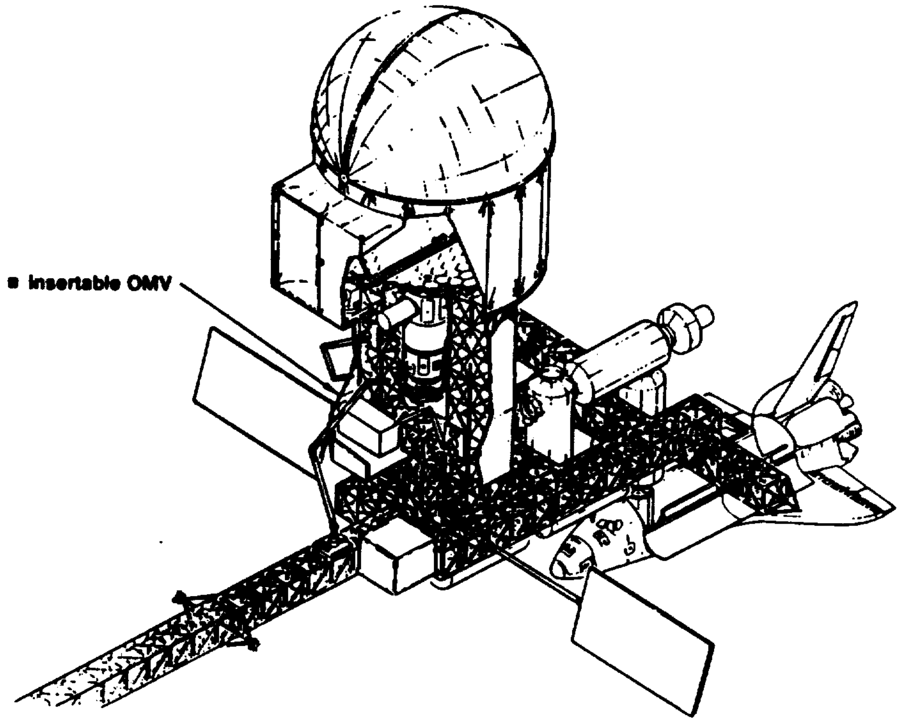
BASIC SERVICING YOKE/ENCLOSURE ON
LARGE CONSTRUCTION SITE
Figure 4.6-1

Seventeen of these foldable units would be joined to make the LDR yoke. If needed earlier or later for other uses, they could be semi-permanently at the LMATS.

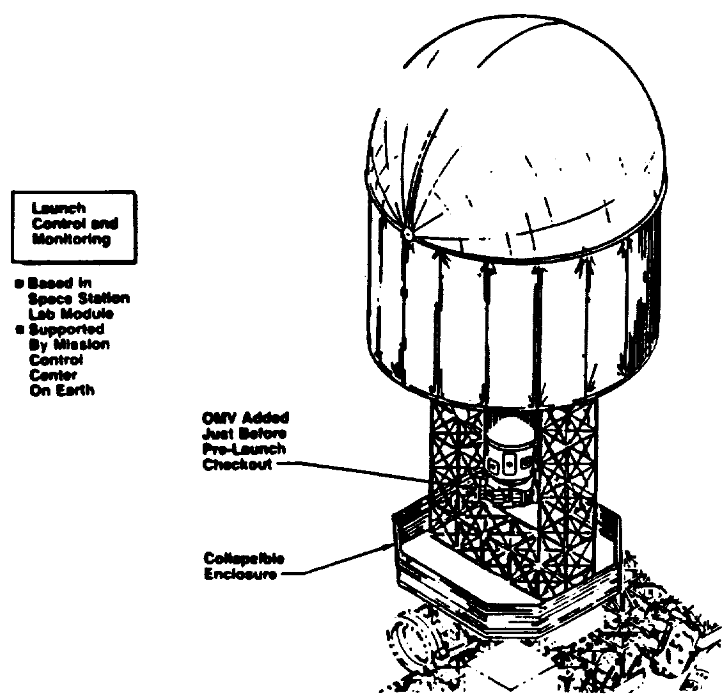
The yoke is a convenient place for robotic module exchanges, or consummable loading (for safety) to save previous EVA time, and to respond to a Congressional mandate that the Space Station be a showcase for advanced U.S. robotics.

As shown in Figure 4.6-2, the yoke would permit easy addition of the OMV before launch. The LDR is thought to be too large for mounting on the OMV at its parking place before launch. Figure 4.6-3 illustrates the LDR/OMV configuration just before separation for launch.

Another way, instead of providing a yoke, is to end-mount the LDR on some sort of complex berthing mechanism that has a separation jack accessory to lift the LDR for OMV addition, as shown in Figure 4.6-4. This would be LDR-peculiar and perhaps a full-term weight penalty also.

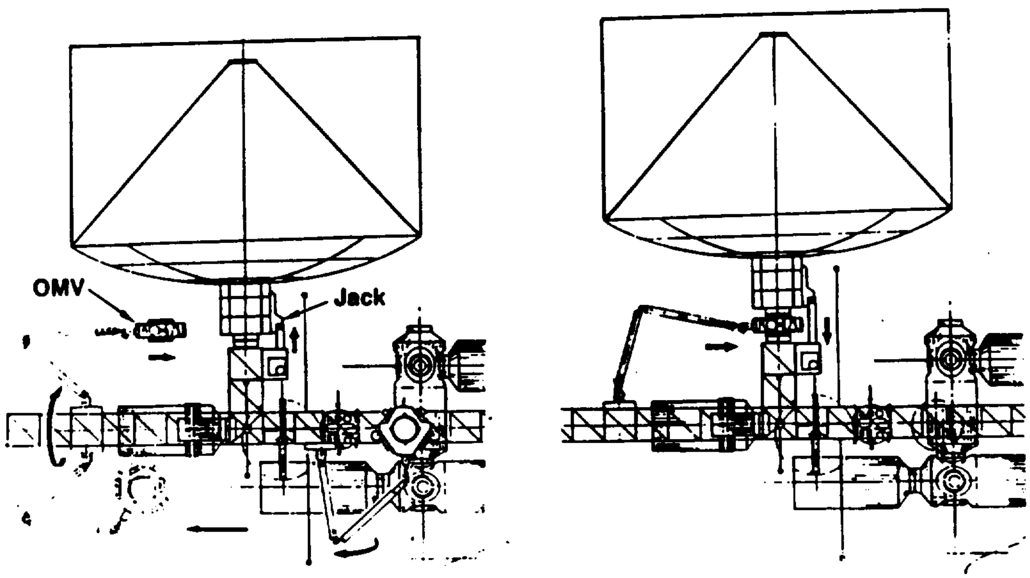


LDR WITH OMV ON OPTIONAL SPACECRAFT SERVICING YOKE (CONT)
Figure 4.6-2



LDR/OMV READY FOR LAUNCH
Figure 4.6-3

■ Auxiliary "Jack" Raises LDR for OMV Insertion/Attachment



OMV ATTACHMENT TO LDR FOR LAUNCH
Figure 4.6-4

4.7 CREW REQUIREMENTS AND SKILLS

The Space Station crew plays a crucial role in the LDR life cycle including assembly/deployment and periodic on-orbit servicing. A list of major mission functions and their associated IVA and EVA requirements, i.e., estimated hours and skill levels, is shown in Figure 4.7-1. Assembly will be performed once while the servicing operations will be performed about every 3-6 years. The hour estimates are preliminary and based upon similar tasks already performed either on existing systems or ground simulations. This data will be refined as more concrete designs, operational scenarios, and ground simulations are defined. The skill levels for each task specify the general type of crew required: standard crew member with no special training in LDR operations (S) or LDR mission specialist (L). The intent is to develop LDR tasks and procedures that minimize the special training requirements and maximize utilization of the S-class crew member. This will lead to cost savings while improving crew productivity.

Assembly and Deployment Tasks

There are 14 top-level tasks associated with initial LDR assembly and deployment, which takes place over a 12-month period. As described in the assembly sequence section, LDR buildup cannot occur continuously due to Shuttle launch limits, therefore the crew activities will be scheduled sporadically as convenient with Space Station operations. The majority of the crew time is required for build-up of the Primary Mirror structure which occurs over six months. Since this task requires LDR specialists (L), both IVA and EVA, the specialist will probably be based at the station over the 6-month period. Most of the other L-skill level tasks can be performed during the Shuttle visits and won't require permanent basing of the specialist.

Servicing Tasks

There are two basic servicing tasks which will be performed during the LDR life: cryogenic replenishment and instrument/equipment exchange. These tasks are short duration activities that require both IVA and EVA crews depending on level of telepresence/robotic technology utilized. Figure 4.7-1 identifies crew requirements for each of the five performance alternatives to the servicing tasks. In the case of S-skill levels, task scheduling is not a factor and can be performed at any convenient time. The L-skill levels tasks, though, will require scheduling to ensure that the LDR specialist is on board. These tasks will probably be performed during the Shuttle visit period because the tasks are short and don't require long term specialist basing.

• Crew hours and skill levels for each major LDR mission task

Mission Function	IVA		EVA	
	Hrs	Skill	Hrs	Skill
Assembly and Deployment	(284)		(436)	
1. Assemble, install and prepare assembly structure	20	L	50	L
2. Install rotatable mirror attachment ring ("Rock of Gibralter")	8	L	16	L
3. Assemble and attach thermal shield, cover, access port, platforms	20	L	24	L
4. Deploy and assemble support structure and mirror assemblies	100	L	250	L
5. Assemble and attach secondary mirror support structure	8	L	16	L
6. Attach secondary mirror module	4	L	8	L
7. Install fine guidance sensor	4	L	8	L
8. Attach and checkout scientific instruments, spacecraft, and cryogenics	24	L	24	L
9. Mate with OMV or OTV	12	L	0	—
10. Remove protective coating, perform system checks	24	L	24	L
11. Move away from space station	12	S	4	S
12. Align and check out	24	L	0	—
13. "Top up" expendables (cryogenics, propellent)	12	S	12	S
14. Boost to operational orbit	12	S	0	—
Maintenance (data for one task operation)				
1. Remote cryogenic replenishment	8	S	0	—
2. Local cryogenic replenishment	6	S	2	S
3. Remote instrument or equipment exchange (teleoperated)	20	L	0	—
4. Remote instrument or equipment exchange (EVA)	6	L	8	L
5. Local instrument or equipment exchange (EVA)	6	S	8	L

(L) - LDR mission specialist (or specially trained crewmember)
(S) - Standard space station crewmember

LDR CREW ROLE
Figure 4.7-1

4.8 SERVICING AND CONFIGURATION CHANGES

Servicing is planned at three year intervals, and is done in conjunction with refurbishment and re-configuration at six year intervals. The OMV will play a key role. When repair/re-configuration is not required the OMV, fitted with a "smart front end" (Figure 2.4.7-2), will travel to the LDR operational orbit to replenish cryogens (liquid nitrogen, liquid hydrogen, liquid helium, superfluid liquid helium) and propellants. When repair/re-configuration changes are required the OMV will bring LDR back to the Space Station for replenishment of cryogens, replenishment of propellants, repairs, replacements and instrument changeout followed by check-out. Re-alignment will take place near the Space Station followed by transportation back to operational orbit by the OMV. The role of the OMV and the Space Station in LDR Servicing and Configuration changes is summarized in Figure 2.4.7-1. The LDR maintenance approach is shown in Figure 4.9-1.

4.9 LDR LOGISTICS

4.9.1 LDR Logistics Analysis

The logistics analysis flow employed in this study, was performed in a top-level fashion using preliminary data, as available. The emphasis of this analysis was to consider the LDR and its operational scenario (inputs) in the system requirements analyses to generate the logistic support requirements or accommodations. LDR logistic support was developed in two areas: Operations and Maintenance (O&M). Overall, the analysis developed operational logistics requirements through an "iterative trades" process that resulted in approaches and scenarios for logistic support (outputs).

Philosophy

- LDR is a complex expensive free-flyer whose operational life can be enhanced and extended indefinitely through maintenance
- On-orbit maintenance, either at Space Station or remote, is the preferred location
- Both scheduled and unscheduled maintenance tasks will be incorporated into the LDR support plans

On-orbit activity

- Scheduled tasks
  - Cryogenic replenishment (every 2-3 years)
  - Scientific instrument exchange (6 years)
  - Spacecraft subsystem exchange (6 years)
  - Mirror surface cleaning (6 years)
- Unscheduled tasks (random failures)
  - Scientific instrument exchange
  - Spacecraft subsystem exchange

LDR MAINTENANCE APPROACH
Figure 4.9-1

The preliminary analysis was based upon the baselined LDR configuration and operational scenarios. The LDR will be assembled, checked-out, and deployed from the Space Station around 1997 and returned every six years for major servicing. Logistic support is required to accommodate the processing and integration of LDR components, support equipment, and supplies for these operational scenarios.

4.9.2 LDR Logistic Support

The LDR is essentially an independent free-flyer that only requires logistic support for the initial on-orbit assembly and subsequent scheduled and unscheduled servicing, approximately every three years over the 15 year LDR life. The logistic support cycle and its associated functions are illustrated in Figure 2.4.3-2. The figure shows logistics is primarily responsible for the integration and delivery of the major elements needed to support the assembly and servicing operations. The equipment, specialists and associated crew training, and operational plans will be processed through the standard Space Station mission integration facilities, launched and managed once at the station. It is the responsibility of the mission planner to schedule and oversee all Shuttle launches and integration activities. The assembly sequence, in particular, requires careful planning and scheduling of as many as five Shuttle launches to ensure that the right part is in the right place at the right time.

4.9.3 Space Station/OMV Role

The Space Station and its facilities, inlcuding the OMV, serves as the base for both the assembly and servicing operations. The station and any mission peculiar facilities are a critical aspect of LDR logistic support. In particular, the special assembly structure and related equipment must be integrated into the station and evaluated against other mission operations and station requirements.

4.9.4 LDR Shuttle Loads (Assembly Support)

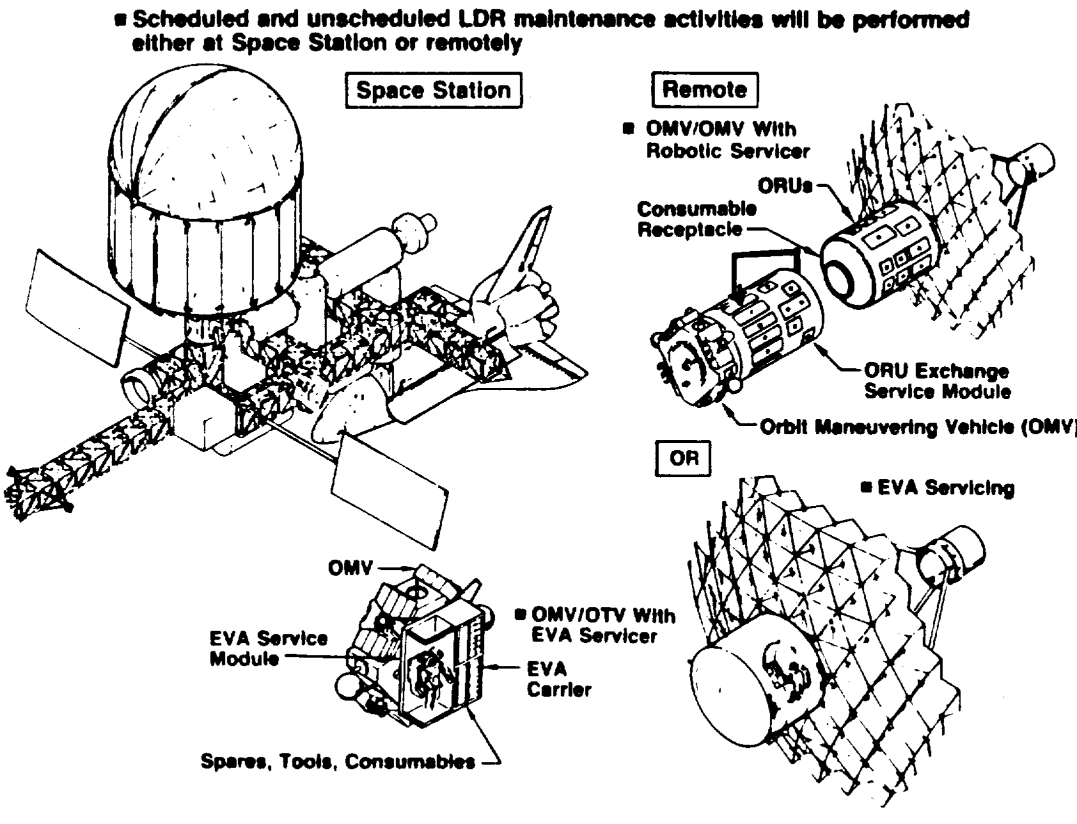
The assembly and deployment will be supported by five Shuttle launches over a 12-month period (refer to Section 2.4.3 Assembly Sequence). The five flight manifests are carefully scheduled and integrated to coordinate with the assembly sequence operations. The details of the manifests are presented in Section 2.4.3. The primary concern of the logistic support system is to ensure that the master five-flight schedule and individual cargo integration is managed to provide the crew with the proper equipment. This must be accomplished to minimize on-station time and concurrently minimize extra costs.

4.9.5 LDR Maintenance Approach

The LDR maintenance approach was generated by considering mission requirements, on-orbit servicing capabilities, and LDR operational characteristics. These factors were considered in the determination of ground rules and alternatives to an LDR servicing plan which is outlined in Figure 4.9-1. The approach is preliminary and only through further analysis will the precise details and preferred approaches be identified. The servicing philosophy is essentially that through on-orbit scheduled and unscheduled servicing, the useful life of the very expensive LDR can be extended. This seems practical in light of the huge initial cost and relatively inexpensive follow-on servicing. A preliminary survey of the LDR and its components led to identification of the scheduled and unscheduled tasks and their anticipated frequencies. This servicing plan should provide the most cost effective method for maximizing successful LDR mission operations.

4.9.6 LDR Maintenance Actions

Servicing support will occur in one of two modes: (1) Space Station-based, or (2) remotely, Figure 4.9-2. For station-based tasks the LDR will be flown to the station via the OMV, attached to the station for the appropriate mission duration, and returned to orbit again via the OMV.



LDR MAINTENANCE ACTIONS
Figure 4.9-2

4.9.7 <u>LDR Logistics Summary</u>

This preliminary top level logistic support analysis has outlined the issues and approaches to LDR logistics. The topics which were addressed in this study are listed in Figure 4.9-3.

- Transportation and support cycle
  - Five assembly flights and their scheduling
  - Space Station logistics flights (LDR consumables, spares)
  - Visiting crew for LDR scheduled maintenance
- LDR maintenance
  - Scheduled tasks (cryo- resupply, equipment exchange...)
  - Unscheduled tasks (equipment exchange)
  - Space Station based and/or remote maintenance locations
- Mission operations
  - Training of station crew if specialist not available (operations + maintenance)
  - Automation anticipated to monitor, control, and test system
  - Paperless information system (OMIS)

LDR LOGISTICS SUMMARY
Figure 4.9-3

5.0 CAPABILITIES THAT MAY BE USED BY OTHER MISSIONS

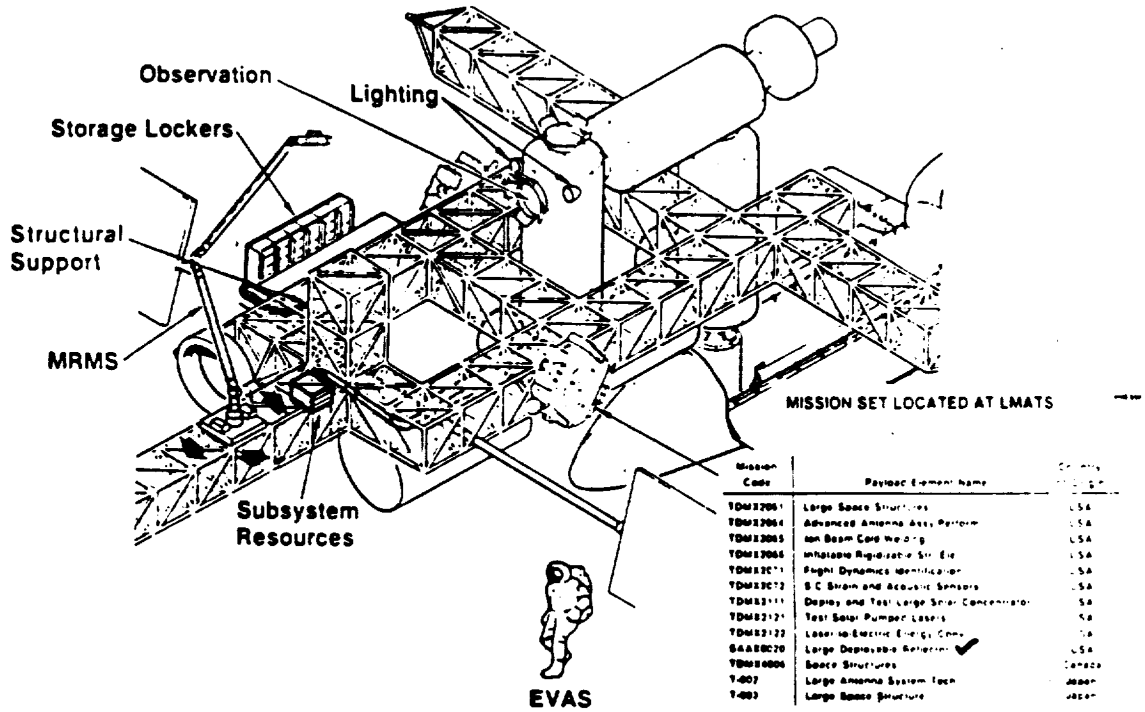
LDR will primarily utilize capabilities on the Space Station that have been used by many other missions, including standardized Space Station payload delivery containers, the Large Mission Assembly and Test Site (LMATS), resource integration junction boxes, resource extension umbilicals, pressurant gases and some cryogen replenishment, orbital replaceable unit stowage lockers, interior control console space, the OMV station proximity operations radars and telemetry feed through from spacecraft to TDRSS (via station), and proximity operations EVA-KIT for OMV. Consequently, except for its substantial mass, LDR will not represent a pioneer-driver-mission for special equipment on the station. All of the items mentioned will have been used, some for many years, by other missions.

Specifically, the LMATS will be heavily used by a dozen or more large size missions, in fact the facility and many station accommodations are sized specifically for the construction, check-out and in some cases even dynamic operation on LMATS. Figure 5-1 illustrates the capabilities of the facility and Figure 5-2 lists the levels of accommodations and time duration involved in the LMATS users. Note that many are long term residents like LDR. Figure 5-3 shows the sizes of LMATS users and with Figure 5-4 the heavy early (Pre-LDR) use of the facility.

In the area of satellite servicings, the data shown in Figures 5-5 and 5-6 indicate that many of the services needed onboard the station during LDR buildup will have had precursor activity. For remote servicing the Space Station data base indicates a considerable activity for geosynchronous spacecraft, based from the station. Cryogen replacement does not appear among these, but it is felt that such a capability will be state-of-the-art for remote servicing in the time period of LDR need.

Figure 5-7 highlights the fact that remote servicing is actually a mode which will relieve a considerable workload on the station. Note also the EVA/OMV unit which will be very useful for LDR nearby off-site check-out in the event that some manual maintenance is needed before the LDR is sent to an orbit quite distant from the station. Conceivably, LDR could be brought back after years of operation to the near proximity of the station for servicing by such an EVA/OMV unit, which may see service out of Shuttle even before there is a Space Station.

Figure 5-8 shows the overall spectrum of servicing both on and off the station which will utilize equipment and develop procedures well in advance and in the same time period as LDR.



*LARGE MISSION ASSEMBLY AND TEST SITE

LMATS* SPACE STATION FACILITIES SUPPORT
Figure 5-1

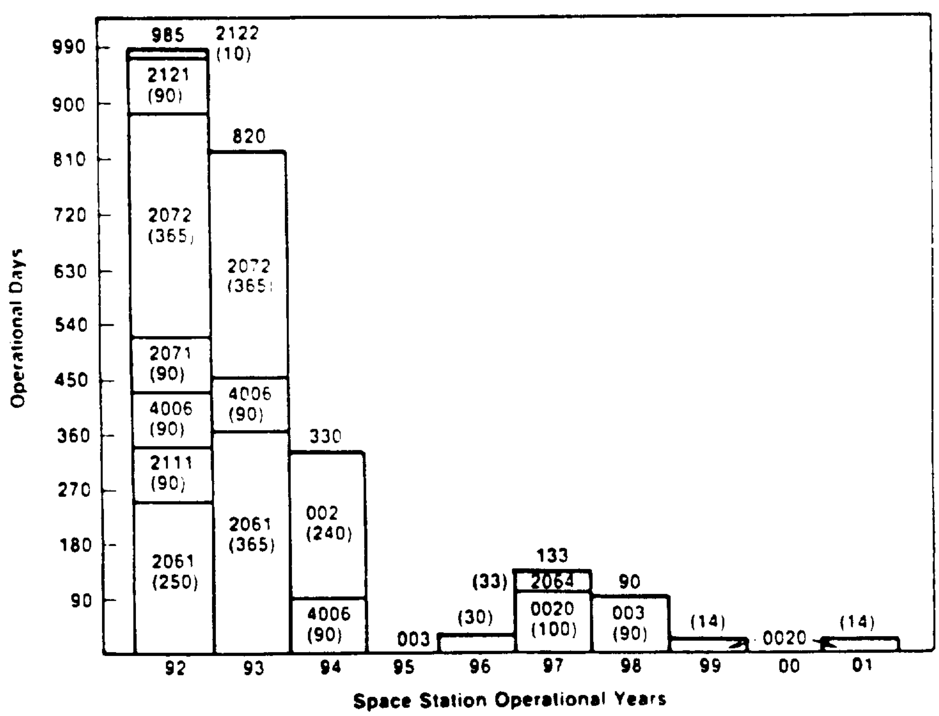
Mission	Category	Duration (Total)	Size Class	Power	Thermal	Data/ Comm	Crew (IVA)	Crew (EVA)	Overall
*TDMX 2061	B	615	Lg	M	M	M	M	M	M-H
* TDMX 2064	D	33	Lg	L	L	M	H	H	M-H
TDMX 2065	A	?	Sm	?	?	?	?	?	–
TDMX 2066	B	?	Med	?	?	?	?	?	–
TDMX 2071	E	90	Sm	L	L	M	L	M	L-M
TDMX 2072	E	720	Sm	L	L	L	L	L	L
TDMX 2111	B	90	Lg	L	L	L	L	M	L
TDMX 2121	E	90	Sm	L	L	L	L	L	L
TDMX 2122	E	10	Sm	L	L	L	L	L	L
*SAAX 0020	D	128	Lg	H	H	L	H	H	H
TDMX 4006	C	180	Sm	M	M	L	L	L	L-M
*T-002	C	240	Sm	M	M	L	H	M	M-H
T-003	A	120	Sm	H	H	H	H	L	M-H

*Major Impact on LMATS

LMATS RESOURCE REQUIREMENTS
(QUALITATIVE ASSESSMENT)
Figure 5-2

LMATS Mission			Size (m, Kg)				Operations										
Code	Name	SATS	L	W	H	Mass	Hr Day	92	93	94	95	96	97	98	99	00	01
TDMX 2061	Large Space Structures	-	28	18	10	7000	6	250	365								
TDMX 2064	Advanced Antenna Assy Perform	F	100	103		3000	6						33				
TDMX 2065	Ion Beam Cold Welding	-															
TDMX 2066	Inflatable Rigid Struc. Ele	-															
TDMX 2071	Flight Dynamics Ident.	-	3.	3	2.	150	24	90									
TDMX 2072	S C Strain and Acoustic Sensors	-	.5	.5	.5	25	23	365	365								
TDMX 2111	Deploy and Test Lg Sol Conc	-	10	10	10	16000	16	90									
TDMX 2121	Test Solar Pumped Lasers	-	2.	1.		200	12	90									
TDMX 2122	Laser-to-Electric Energy Convers	-	1.	1	1	100	12	10									
SAAX 0020	Large Deployable Reflector	F	40	35	35	55000	24						100		14		14
TDMX 4006	Space Structure	1, 2, 4, 5N, A11M	20.	100		1020	2	90	90	90							
T-002	Large Antenna Sys Tech	1, 3, 4, 5M	10	11		800	2			240							
T-003	Large Space Structure	1, 3, 4, 5M F	2.	1	1	400	4					30		90			

LARGE MISSION ASSEMBLY AND TEST SITE CANDIDATES
Figure 5-3



LMATS MISSION SCHEDULE
Figure 5-4

Mission Code	Category	SATS	Description	Number of Operations 92	93	94	95	96	97	98	99	00	01
Comm 1124	R/R, Repl	F	Equipment, Consumables							1			1
Comm 1125	R/R, Repl	F	Equipment, Consumables								1		2
Comm 1126	R/R, Repl	F	Equipment, Consumables									1	
SAAX 0221*	Adj	F	Antenna Tolerance								1	1	1
SAAX 0222*	Up	F	General Maintenance								1	1	1
SAAX 0223*	Up	F	General Maintenance								1	1	1
SAAX 0226*	Repl	F	Accelerator Gases (Ar, Xe, N)									1	
SAAX 0309*	Up (R/R)	F	Modular Instruments								1	1	1
SAAX 0501	R/R	F	Equipment Modules (e.g. Batteries)									1	
SAAX 0503	Repl	All M	Hydrazine or Bipropellant			u	u	u	u				
SAAX 0504	Repl	PF	Hydrazine or Bipropellant								1		1

*Part of SAAX 0501 GEO Platform

Note: Several missions (incl SAAX 0020, 0004, and 0027) which are presently listed as Space Station local servicings may become co-orbiting remote servicings

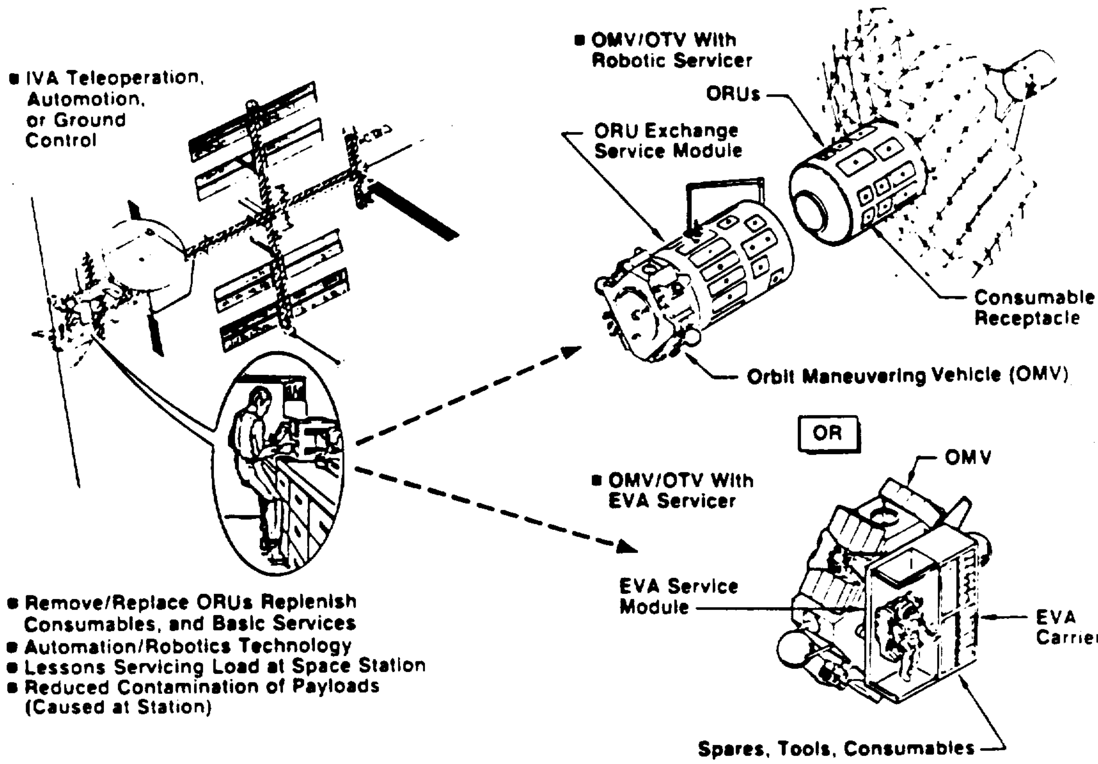
REMOTE SATELLITE SERVICING
(GEO MISSIONS)
Figure 5-5

Mission Code	Category	SATS	Description	Number of Operations 92	93	94	95	96	97	98	99	00	01
SAAX 0004	Repl	All N,M	Cryogenics				1		1	1		1	1
	R/R †		Instruments										1
SAAX 0006	R/R †	All M	Instruments							1			
SAAX 0007	R/R †	All M	Detectors							1			1
SAAX 0012	Up (R/R) †	All N,M	Instrument Replacement, Checkout				1			1			1
SAAX 0013	Repl †	All N	Hydrazine		1								
SAAX 0016	Up (R/R) †	All N,M	Instrument Replacement, Checkout				1			1			1
SAAX 0017	Repl †	All N,M	Cryogenics				1			1			1
	Up (R/R) †		Instruments				1			1			1
SAAX 0020	Repl	F	Superfluid Helium								1		1
	Up		Equipment								1		1
SAAX 0022*	Up (Repl) †	All N,M	Consumables, Instruments	4	4	4	4	4	4	4	4	4	4
SAAX 0023*	Up (Repl) †	All N,M	Consumables, Instruments		4	4	4	4	4	4	4	4	4
SAAX 0024*	Up (Repl) †	All M	Consumables, Instruments			4	4	4	4	4	4	4	4
SAAX 0025*	Up (Repl) †	All M	Consumables, Instruments				4	4	4	4	4	4	4
SAAX 0027	Up (R/R) †	All N,M	Instrument Replacement, Checkout							12	12	12	
SAAX 0402	Up (Repl) †	F	Gases, Equipment							2	2	2	

*Spartan 1-4 Missions May Be Serviced Simultaneously

† Potential Hangar Activity

SATELLITE SERVICING ON SPACE STATION
(BASIC MISSION MODEL REQUIREMENTS)
Figure 5-6



REMOTE PAYLOAD SERVICING
Figure 5-7

	92	93	94	95	96	97	98	99	00	01
Satellite Service (Local)	4	9	12	21	16	17	37	32	31	25
Satellite Service (Remote)	0	0	0	0	0	0	1	6	7	8
Externally Attached (Routine)	27	15	36	13	22	13	27	7	7	7
Externally Attached (Extensive)	25	25	29	38	39	35	34	22	23	20
Space Station Totals	56	49	77	72	77	65	99	67	68	60

- These figures represent servicing operations and not missions which can have multiple operations
- Results based on external missions (attached and free-flyer)
- Data does not include all European, Japanese, and Canadian missions

SERVICING SUMMARY
(NUMBER OF OPERATIONS)
Figure 5-8

6.0 TECHNOLOGY DEVELOPMENT MISSION (TDM-2421)

6.1 BACKGROUND

The LDR, as presently conceived, is a complex and challenging mission which will stretch the state-of-the-art of assembly, test and operation of large, high precision, multi-segmented optics in space. It is critical to the success of this undertaking that key elements of new technology embodied in LDR be identified, developed and tested prior to the deployment of prime mission hardware. In recognition of this, Kodak was contracted in a previous study (NASA - Ames Research Center, Contract NAS2-11861) to formulate a "Technology Assessment and Technology Development Plan". A draft plan (Large Deployable Reflector (LDR) System Concept and Technology Definition Study - Final Technical Report, Volume II) was submitted 28 February 1985. It identified 22 individual technology development projects aimed at "achieving requisite levels of technology capability prior to the start of Phase C development of the Large Deployable Reflector (LDR) in the early 1990's". These projects were designed to "accelerate progress of technology growth essential to LDR, where the rate of growth over the next six years is projected to fall short of LDR needs". Projects were classified in priority groups as shown in Table 6.1-1. The Technology Development Mission (TDM-2421) described here is designed to serve as a natural extension of ground or STS testing in those critical areas requiring Space Station experiments.

TABLE 6.1-1
INDIVIDUAL TECHNOLOGY AUGMENTATION PROJECTS CROSS REFERENCE

OAST CATEGORY	TECHNOLOGY PROJECT TITLE	KODAK PROGRAM GROUP
	HIGH PRIORITY (5 PROJECTS)	
B	DYNAMIC STRUCTURAL CONTROL	POINTING & STABILITY
D	HUMAN FACTORS	POINTING & STABILITY
E	HYBRID CRYOGENIC SYSTEM FOR SCIENCE INSTRUMENTS	DETECTABILITY
G	ACTIVE PRIMARY MIRROR	REFLECTOR QUALITY
G	PRIMARY MIRROR CONTAMINATION PROTECTION	DETECTABILITY
	MEDIUM PRIORITY (17 PROJECTS)	
A	PRIMARY MIRROR SEGMENT SENSING AND CONTROL APPROACH	REFLECTOR QUALITY
A	FOLD MIRROR CHOPPING	DETECTABILITY
A	SECONDARY MIRROR CHOPPING	DETECTABILITY
A	FINE GUIDANCE SENSING AND CONTROL	POINTING & STABILITY
B	DYNAMIC DIMENSION STABILITY	POINTING & STABILITY
B	DYNAMIC RESPONSE PREDICTION PRECISION	POINTING & STABILITY
B	STRUCTURAL NONLINEARITY	POINTING & STABILITY
B	LOW JITTER AND RAPID SETTLING	POINTING & STABILITY
B	VERIFICATION/ACCEPTANCE GROUND TESTING	POINTING & STABILITY
B	MECHANICAL STABILITY - DAMAGE TOLERANCE	POINTING & STABILITY
B	STEP SUNSHIELD	DETECTABILITY
B	SECONDARY MIRROR TEMPERATURE CONTROL	DETECTABILITY
B	PRIMARY MIRROR TEMPERATURE CONTROL	DETECTABILITY
E	CRYOGENIC SYSTEMS FOR DETECTOR TEMPERATURE LESS THAN 0.3 DEGREES KELVIN	DETECTABILITY
E	ROBOTIC ON-ORBIT CRYOGENIC REPLENISHMENT	DETECTABILITY
G	GLASS MATERIAL FOR PRIMARY MIRROR	REFLECTOR QUALITY
G	COMPOSITE MATERIAL FOR THE PRIMARY MIRROR	REFLECTOR QUALITY

6.2 CONCEPTUAL DESIGN

The objective and a general description of the TDM are shown in Figure 6.2-1. Most of the key areas to be investigated (such as human factors associated with assembly, micro-scale deformation of structure, secondary mirror chopping and re-establishment of multi-segmented mirror figures) are very heavily dependent on scale. To test these items on the Space Station at less than full scale, after the very substantial cost of designing and conducting the experiments, would still leave significant gaps of information and knowledge. The technology areas not included in this TDM can either be satisfactorily developed using ground or STS verification or will be developed for other missions prior to LDR. It is concluded, therefore, that scale is a fundamental driver and that "full scale" simulation of selected mission elements, in the Space Station environment, is fundamental to supporting the objectives of this TDM.

EXPERIMENT OBJECTIVE

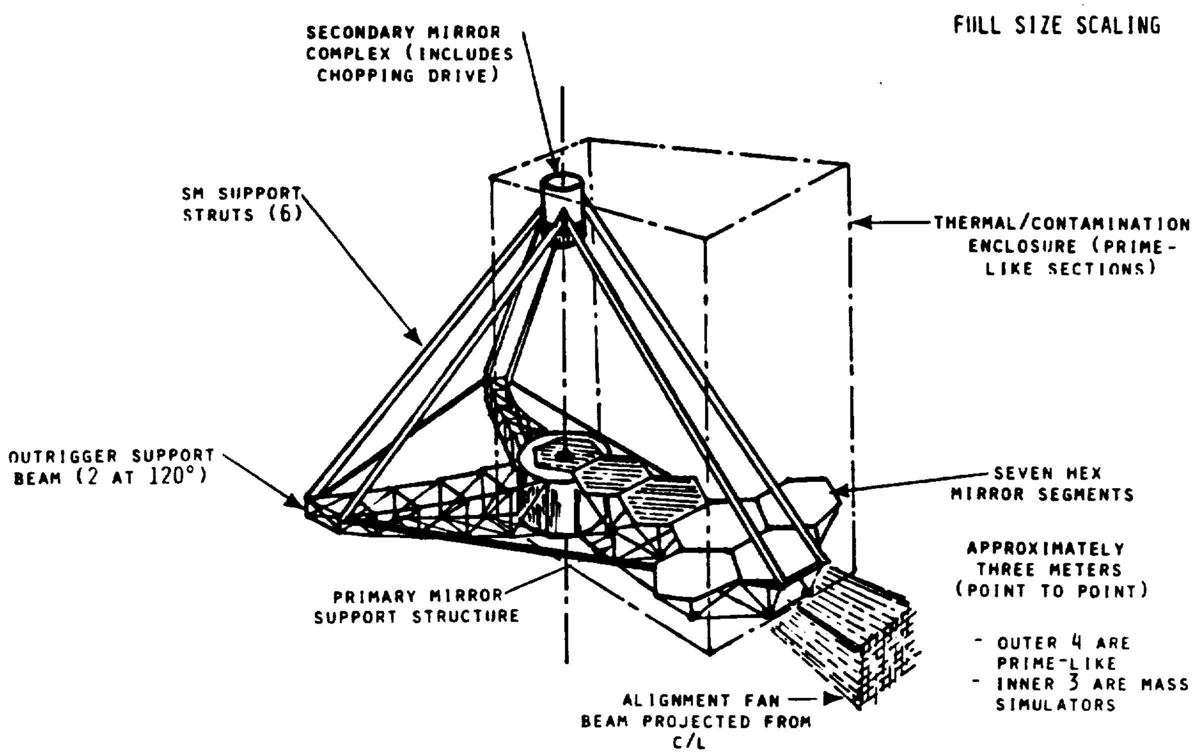
TO PROVIDE A TECHNOLOGY BASE FOR THE TRANSPORTATION, CONSTRUCTION, ALIGNMENT, TEST, AND OPERATION OF LARGE APERTURE SEGMENTED MIRRORS HAVING HIGH SURFACE ACCURACY OPTICAL FIGURES.

EXPERIMENT DESCRIPTION

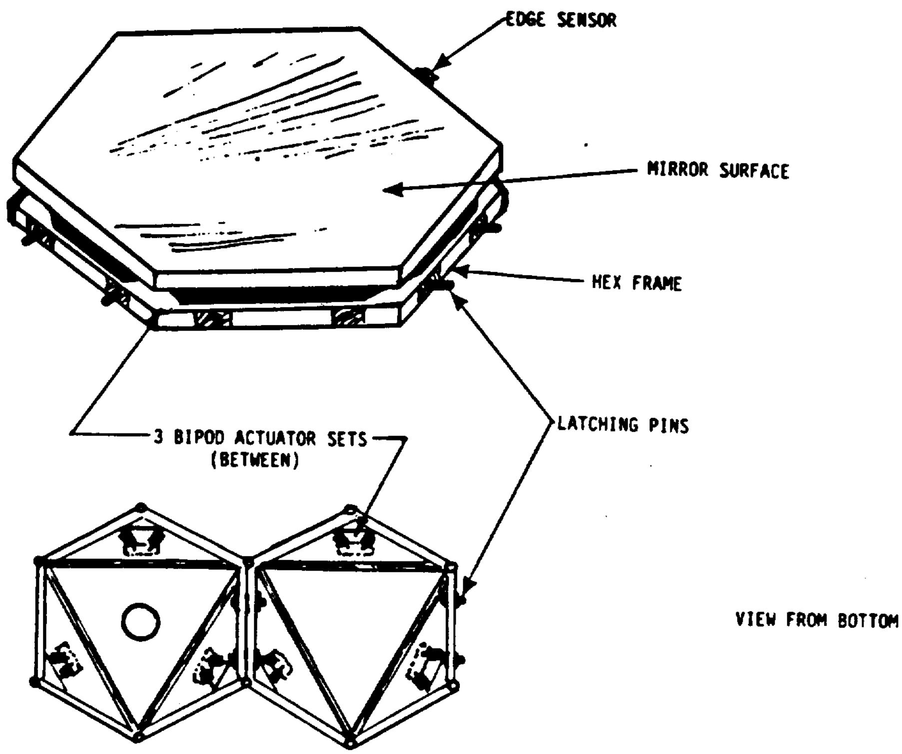
THE PROPOSED MISSION WILL INVESTIGATE CRITICAL TECHNOLOGICAL ISSUES GERMANE TO USE OF LARGE, MULTI-SEGMENTED, ACTIVE REFLECTORS IN FUTURE SPACE PROJECTS. KEY AREAS OF EXPERIMENTATION ARE EFFICIENT DEPLOYMENT AND ERECTION OF SUPPORTING TRUSS STRUCTURE; VERIFYING HIGH RESISTANCE OF THE TRUSS STRUCTURE TO MICRO SCALE DEFORMATION DUE TO THERMAL OR VIBRATION EFFECTS; DEPLOYMENT AND LATCHING OF MIRROR ELEMENTS; MEASUREMENT OF OPTICAL ALIGNMENT THROUGH WAVEFRONT SENSING OR LASER RANGING TECHNIQUES; ADJUSTMENT OF MIRROR SEGMENTS THROUGH MICROACTUATORS AND CONTROL ALGORITHMS; DEMONSTRATION OF EFFECTIVE MEANS OF CONTAMINATION CONTROL AND THE EFFICACY OF SECONDARY MIRROR CHOPPING.

TECHNOLOGY DEVELOPMENT MISSION FOR LARGE DEPLOYABLE REFLECTOR
Figure 6.2-1

The configuration selected to support the objectives of TDM-2421 is shown in Figure 6.2-2. It consists of a full scale center-to-edge slice of the radially symmetric LDR primary mirror, support structure,thermal/contamination enclosure and alignment fan beam. In addition it includes a full sized secondary mirror simulation, including prime-like chopping drive mechanisms and prime-like support struts with outrigger supports to simulate the remainder of the primary mirror support structure complex. The seven hexagonal primary mirror segments are also full sized - about 3 meters point-to-point. The inner three are mass simulators and the outer four are prime-like high quality mirrors. The six off-axis segments all incorporate other prime-like features such as edge sensors, bi-pod micro-actuator sets, latching pins and hex-frame supports. The general configuration of the mirror segments is shown in Figure 6.2-3.



TECHNOLOGY DEVELOPMENT CONCEPT FOR LARGE DEPLOYABLE REFLECTOR
Figure 6.2-2



PRIMARY MIRROR SEGMENT FEATURES
Figure 6.2-3

6.3 EXPERIMENTS

6.3.1 Human Factors Aspect of Assembly

The LDR will differ from other large structures assembled in space in a number of ways but primarily because of the very high precision required. The supporting structures will be made of very low coefficient of thermal expansion material and will have to fit together with great precision with stable joints with linear deflection characteristics. Some sort of bolted joint may be required. The mirror segments themselves will be fastened together with unique high precision latching mechanisms designed to duplicate ground located positions relative to adjacent segments within about 50 micro-inches. Further, the large mirror segments will be very fragile and probably require a unique combination of man-machine precision manipulation.

6.3.2 Stability of Assembled Structure

The support structure will be highly instrumented. It must demonstrate a high degree of resistance to micro-deformation due to changes in temperature distribution and other conditions. Vibratory response to loads imposed by movements and damping and mirror deflections will be measured.

6.3.3 Secondary Mirror Alignment and Chopping

After precision assembly, unique new methods for sensing of secondary mirror tilt and decenter (with respect to the primary mirror) must be tested and the effectiveness of micro-actuators, moving in response to these signals, evaluated. The chopping drive mechanism will be operated for an extended period of time and its reliability and effectiveness operating in an "o-g" environment evaluated. Also, the ability to isolate chopping drive impacts on the remainder of the structure in the "o-g" environment will be evaluated.

6.3.4 Secondary Mirror Support Structure

The stability of the support structure to thermal and other loads as well as its role in isolating secondary mirror vibrations will also be evaluated. Latching and attachment mechanisms will be verified.

6.3.5 Primary Mirror Edge Sensors

Primary mirror segment position will be sensed by the mirror edge sensors. Their ability to work effectively in the "o-g" vacuum environment and the ability of associated means of interpretation, including the astronaut and Lab Module equipment, must be tested.

6.3.6 Primary Mirror Segment Movement

The ability to re-establish and maintain the ground established best position of the primary mirror segments through precise adjustment (2 tilts, 1 de-space) must be verified over an extended period of time.

6.3.7 Primary Mirror Fan Beam System

A system to accurately measure the relative position of elements in large space structures is currently under development at the Eastman Kodak Company. It utilizes unique means of detecting micro-scale movements of projected laser beams. Its use, incorporated in the current LDR concept, will help to assure accurately located structural elements. Its ability to be used by astronauts, in the Space Station environment, must be verified.

6.3.8 Strippable Mirror Coatings

Strippable coatings are a key element in the plan to protect mirror elements from contamination during transportation and assembly. Their effectiveness in doing so and the ability of astronauts to remove them in the challenging space environment will be tested.

6.3.9 Thermal Control

The ability of LDR to function is heavily dependent on maintaining the very precise thermal control demanded by the scientific requirements. Long duration testing on the Space Station will offer an excellent opportunity to test the thermal shield and other elements of the thermal control system. A well designed, long duration test will offer the opportunity to fully explore its effectiveness.

6.4 EQUIPMENT NEEDED

This mission involves much of the same type of on-station support equipment as the LDR described in previous sections. Although this technology mission is performed a number of years before the actual LDR, the station capability will already be there for many other missions as explained in Section 5.0, Capabilities That May Be Used By Other Missions.

Basically the Large Mission Assembly and Test Site will be needed and available, plus its structural stand-offs from the main keel structure for payload operations clearance, and the resource extension umbilicals from the nearest junction box on the station main distribution runs in the keel.

The standard station payload containers for Shuttle delivery will be available; a closed-type being needed for TDM2421. A wide range of EVA support tools, aids and access platforms will be part of the basic station inventory, but LDR will most likely require and bring some special construction tools and fixtures.

The station's interior general purpose workbench will most likely be used for minor maintenance or modifications throughout the one year of assembly and testing. Also, the use of some storage locker space (exterior) is anticipated for various test/modification equipment.

Interior space will be required for mounting of the TDM2421 control, monitoring and diagnostic equipment. This is estimated to occupy approximately the equivalent of two racks of equipment mounting volume in the Science/Technology Cab (GSFC).

6.5 RESOURCE REQUIREMENTS

6.5.1 Orbit

The TDM2421 will be designed to operate in the planned nominal Space Station orbit of 500 km and 28.5°. No special orbit adjustments will be needed at any time.

6.5.2 Power

Power will be required on a continual basis for thermal control. Additional power will be required during experiments. Approximate power consumption requirements are shown in Figure 6.5.2-1.

6.5.3 Thermal Viewing

Thermal viewing may be varied by adjusting the position of LDR with respect to the Space Station and other thermal loads. This will not, however, impose any special restrictions on LDR.

MICRO-ACTUATORS AND POSITION CONTROL ELECTRONICS	15 WATTS
MULTIPLEXING	50 WATTS
DEMULTIPLEXING (IN LAB MODULE)	50 WATTS
THERMAL CONTROL	200 WATTS
CHOPPING	10 WATTS
ALIGNMENT REFERENCE	5 WATTS
TOTAL	330 WATTS

TDM - 2421
POWER CONSUMPTION
Figure 6.5.2-1

6.5.4 Data

Data rates and storage requirements are relatively modest. The experiment elements demanding the highest data rates are those investigating vibration and damping of the structure which require rapid monitoring of a large number of vibration sensors. Data/Communications rate requirements are broken down in Figure 6.5.4-1. Maximum storage requirements on the order of 1 megabit are expected.

• MICRO-ACTUATORS AND POSITION SENSORS	2 KBPS
• THERMAL DATA	0.8 KBPS
• VIBRATION SENSORS	32 KBPS
• ELECTRONICS	1.6 KBPS
• DISPLACEMENT MEASUREMENT	0.1 KBPS
TOTAL	36.5 KBPS
• ASTRONAUT SUPPORT	
VIDEO	~ 10 MHZ
AUDIO	~ 5 KHZ

TDM - 2421
DATA/COMMUNICATIONS
Figure 6.5.4-1

6.5.5 Crew

Technology Development Missions require the skill types associated with the setup, conduct, and evaluation of engineering tests on the ground. Consequently, the two-man payload-dedicated crew for this mission would be of the engineering skill-type, one at the technician level and one at the professional level.

The IVA activity would be directed and in part performed by the engineering professional who also would coordinate activities with (a) the general monitors of the Space Station Mission Control - Payload Operations organization and (b) the developing organizations experts at the home-base payload operations control center.

Control installation, check-out and activation of the TDM2421 interior consoles would be primarily performed by the technician, while interfacing with station operational planners would be coordinated by the TDM2421 professional. Once activated, the interior consoles would be operated by the TDM professional.

EVA set-up of the TDM exterior equipment would be performed by the TDM technician (with prior EVA training) supported by a Space Station core crew member who had been cross-trained earlier on TDM2421 either via video link in orbit or by training on earth.

The set-up operations would be supported by the helmet-mounted, mini-TV instruction system, for reference for efficiency and check-list functions. Initially, the EVA crew would watch the TDM equipment in the cargo carrier prior to MRMS extraction and transfer to the construction/installation location. Since this mission involves only a one-time, unique set-up, no supplemented robotics are planned for the function.

Since the TDM is a precursor for later LDR operations, all activities will be logged, timed and TV-monitored to gather data for analysis of effectiveness and potential improvement ideas for eventual LDR operations.

The set-up operations include a variety of assembly functions involving structures, mechanical items, optical elements, instrumentation and a thermal shroud, i.e., a broad range of relatively gross functions plus very critical, high-accuraccy items. This range indicates the need for very special training for the core station crew member, most likely at a ground station facility.

During the course of the year's test activities, there will be numerous requirements for EVA activities to change or replace different items of instrumentation or test modification accessory items. These may be planned to coincide with the visit of yet other TDM trained specialists who may even accompany such modification equipment to orbit and then return on the same Shuttle which delivered them, or stay on to replace the prior TDM specialist. In this way, a great variety of expertise can be brought to bear on this complex and extensive engineering test, which is a critical prologue to the $1 billion-plus LDR program.

6.5.6 Servicing

About one hour of EVA by a crew of two persons will be required every 30 days for routine servicing and maintenance. Longer periods may be required if malfunctions occur.

6.5.7 Contamination

Contamination is a very major concern. Extremely low levels are required to assure the success of the TDM as well as the LDR mission.

6.6 RESOURCE TIMELINES (TDM2421)

The Technology Development Mission for LDR is planned for launch in March 1995 and return to earth a year later. The entire assemblage will be delivered in a standardized enclosed Space Station payload container which is docked via its Shuttle trunnions and keel fitting on the side of the left/aft keel area designated as Large Mission Assembly and Test Site (LMATS); as shown on the Dual Keel Station depicted in Figure 6.6-1.

As Figure 6.6-2 indicates, the TDM2421 containerized delivery will be designed and monitored as a precursor for later LDR element delivery, protection, storage, access, and extraction, plus an evaluation of the secure mounting of sensitive LDR-type parts in the container with easily-releasable fittings. Thus, the basic transport-to-orbit function is, in a sense, a technology demonstration which will be instrumented and evaluated for certification as a basis for further LDR application.

The location is the same as that shown earlier for LDR on the dual keel station. The artwork shown in these figures is a replacement for earlier work done during the study which was, as directed, on the Power Tower Space Station configuration.

The set-up time is planned for a ten-day period during the stay time of the Shuttle which delivers the TDM equipment. This provides several benefits, namely one or more LDR/TDM specialists can go up and back with the Shuttle to provide more on-site crew capability with LDR/TDM set-up expertise. Once they return it is felt that LDR/TDM would only have one full time person there. This actively should be within the state of assembly art for the late 1990's since major early portions of the Space Station would have been assembled in 10-day Shuttle excursions (before station is manned). By the second day the assembly work would progress through the configuration shown in Figure 6.6-3.

The stage reached as shown in Figure 6.6-4 would take the next day, and the Figure 6.6-5 state would be achieved by the fifth day. The construction of the enclosure would take the next three days (through the eighth) leaving two days for final check-out of assembly only with the possibility of a very-basic power-on/systems check before the short-term (10-day) LDR/TDM visitors have to return with the Shuttle (Figure 6.6-6).

For the remainder of the next 12 months, the on-board specialist may be exchanged numerous times, since there will be a Shuttle visit for station resupply, payload exchange, or logistics possibly every 41 days. Different specialists could be utilized for differing phases of the extensive series of engineering tests envisioned for TDM2421.

C-2

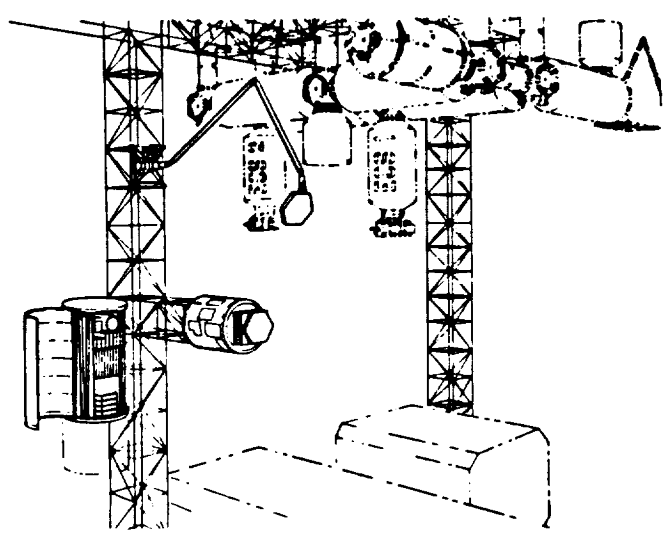
Transportation

- One-Half STS Cargo Bay Load (Enclosed Container)
- Constitutes "Trailblazer" for LDR transport

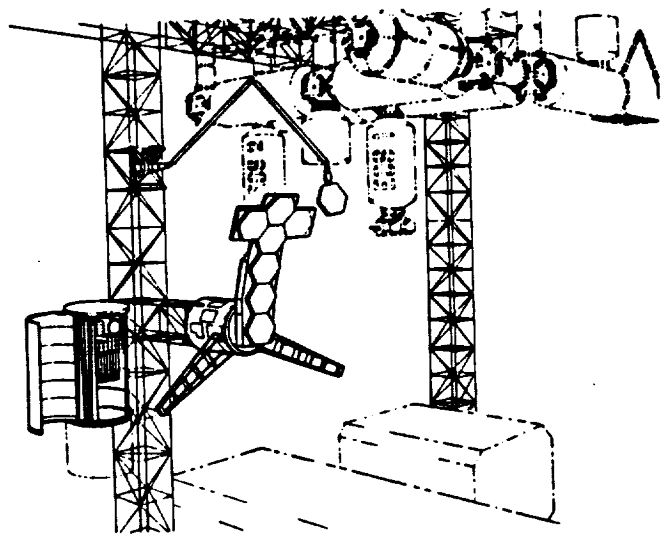
On-Site/Space Station Operations

- Locations:
  - Large Mission Assembly/Test Site (Mid-Keel)
  - (Container Stowed Along Side)
  - Science Lab TDM control consoles
- Set-Up:
  - 10 Day Duration (2 EVA Crew: 1/2 Time)
  - (One Crew Person Trained Specially for LDR)
  - MRMS Assist Functions
- Test Conduct: 52 Weeks (On-Site LDR Specialist In Coordination With Ground Team)

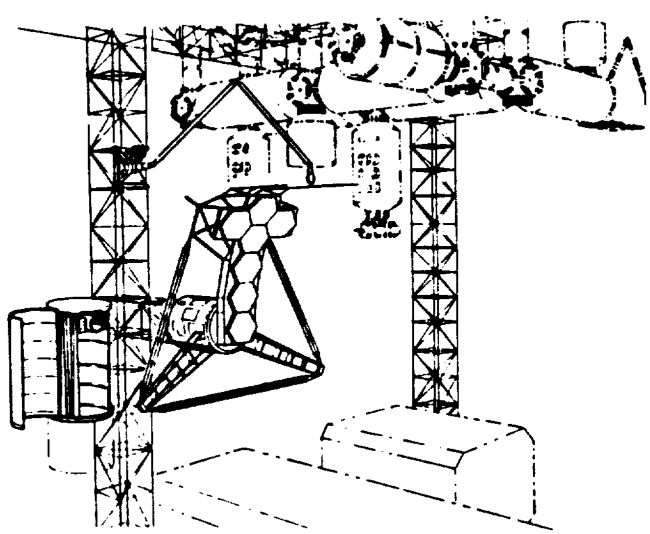
ACTIVE OPTICS TECHNOLOGY EXPERIMENT BUILDUP
(DEVELOPMENT MISSION TDMX 2421)
Figure 6.6-1



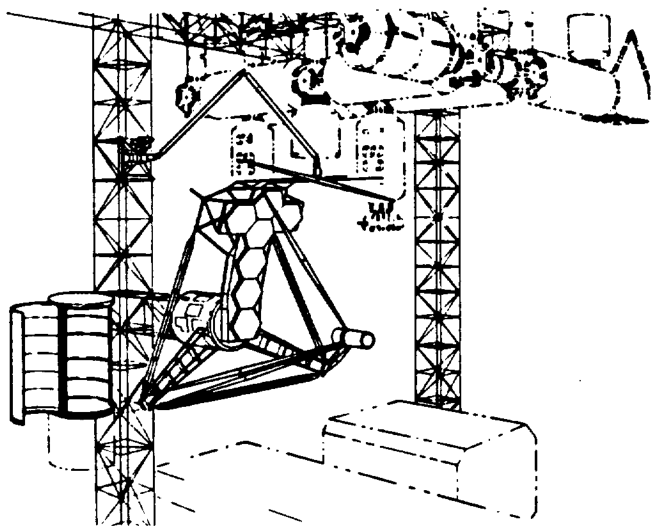
ACTIVE OPTICS TDM 2421
ACCOMMODATION AND CONSTRUCTION
Figure 6.6-2



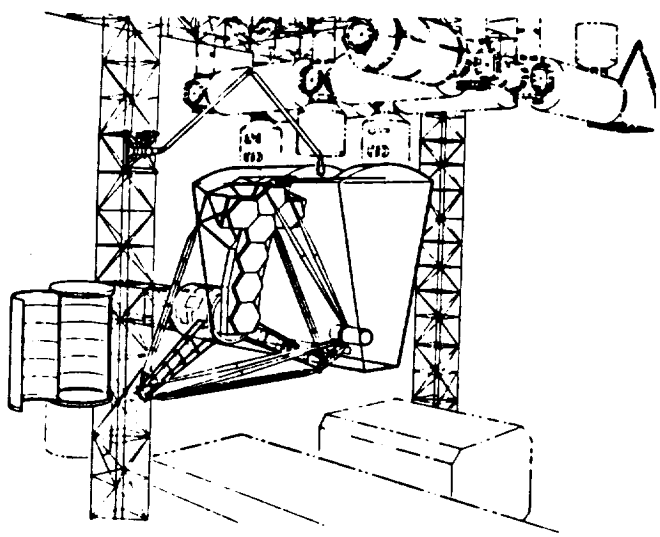
ACTIVE OPTICS TECHNOLOGY EXPERIMENT BUILDUP
(DEVELOPMENT MISSION TDMX 2421) (CONT)
Figure 6.6-3



ACTIVE OPTICS TECHNOLOGY EXPERIMENT BUILDUP
(DEVELOPMENT MISSION TDMX 2421) (CONT)
Figure 6.6-4



ACTIVE OPTICS TECHNOLOGY EXPERIMENT BUILDUP
(DEVELOPMENT MISSION TDMX 2421) (CONT)
Figure 6.6-5



ACTIVE OPTICS TECHNOLOGY EXPERIMENT BUILDUP
(DEVELOPMENT MISSION TDMX 2421) (CONT)
Figure 6.6-6

At the end of the test, the Shuttle would have brought up a standard container for return of the TDM2421 equipment, which should be disassembled and stowed in a 10 day Shuttle stay time.

6.7 PRECURSOR ACTIVITIES AND SCHEDULE

Candidate precursor activities, both ground and Shuttle-based, are shown in Figure 6.7-1. An overall schedule is shown in Figure 1.4-2.

GROUND TESTS/ANALYSES

UNDERWATER ZERO-G SIMULATION

- LATCHING MECHANISMS FOR PRIMARY MIRROR SEGMENTS/SUPPORT TRUSS
- TIMELINES/OPERATIONAL PROCEDURES FOR ON-ORBIT ASSEMBLY

COMPUTER MODELING/ANALYSIS

- THERMAL, VIBRATION, ALIGNMENT DESIGNS

VACUUM TESTING

- ALIGNMENT FAN BEAM CONCEPT VERIFICATION

OTHER LDR TECHNOLOGY TESTS/ACTIVITIES

- PROGRAMS AND PROJECTS IDENTIFIED IN TECHNOLOGY DEVELOPMENT PLAN

SHUTTLE EXPERIMENTS

TDM COMPONENT-LEVEL TESTING

- PRIMARY MIRROR/SECONDARY MIRROR ACTUATION DESIGNS
- PRIMARY MIRROR/SECONDARY MIRROR SENSING DESIGNS
- CHOPPING MECHANISM DESIGN
- STRIPPABLE COATINGS
- THERMAL SHIELD CONSTRUCTION

OTHER LDR TECHNOLOGY EXPERIMENTS

- FINE GUIDANCE SENSOR/BORESIGHTING/RELAY OPTICS
- CRYOGENIC COOLING DESIGNS
- AUTOMATED REPLACEMENT OF CRYOGENS
- SENSORS/DETECTORS FOR SCIENTIFIC INSTRUMENTS

CANDIDATE PRECURSOR ACTIVITIES FOR TDM-2421
Figure 6.7-1

APPENDIX A

UPDATE OF MISSION DESCRIPTION TDM-2421

PAYLOAD ELEMENT NAME LDR TECHNOLOGY — **CODE** MRWG 2421	**TYPE**
CONTACT **Name** Donald L. Agnew **Address** Government Systems Division, Eastman Kodak Company 901 Elmgrove Road Rochester, NY 14650 **Telephone** (716) 253-2377	__ Science & Applications (non-commercial) __ Commercial ✓ Technology Development __ Operations
STATUS __ Operational __ Approved __ Planned __ Candidate ✓ Opportunity	**Type Number** 14 **(see Table A)**
First flight, yr 1995 **No. of flights** 2 **Duration of Flight, days** 360	**Importance of the Space Station to this Element** 1 = low value but could use 10 = vital
OBJECTIVE To provide a technology base for the transportation, construction, alignment, test, and operation of large aperture segmented mirrors having high surface accuracy optical figures.	**Scale 1 - 10** 9

DESCRIPTION

The proposed mission will investigate critical technological issues germane to use of large, multi-segmented, active reflectors in future space projects. Key areas of experimentation are efficient deployment and erection of supporting truss structure; verifying high resistance of the truss structure to micro scale deformation due to thermal or vibration effects; deployment and latching of mirror elements; measurement of optical alignment through wavefront sensing or laser ranging techniques; adjustment of mirror segments through microactuators and control algorithms; demonstration of effective means of contamination control and the efficacy of Secondary Mirror chopping.

ORBIT CHARACTERISTICS - on Space Station

Apogee, km 500 Perigee, km 500 Tolerance + TBD - TBD

Inclination, deg 28.5° Tolerance + TBD - TBD

Nodal Angle, deg TBD Ephemeris Accuracy, m TBD

Escape dV Required, m/s

POINTING/ORIENTATION - Accurate (TBD) positional stability

View direction X Inertial __ Solar __ Earth

Truth Sites (if known)

Pointing accuracy, arc sec N/A Field of view, deg N/A

Pointing Stability (Jitter), arc-sec/sec DECOUPLED FROM STATION VIBRATIONS

Special Restrictions (Avoidance) TBD

POWER

__ AC X DC

	Power, W	Duration, hours/day
Operating	330	8
Standby	200	24
Peak	330	8

__ Continuous

Voltage, V 24 Frequency, Hz

DATA/COMMUNICATIONS

Monitoring requirements:

__ None X Real-Time __ Off-Line __ Other

NO Encryption/Decryption Required

NO Uplink Req.: Command Rate (kb/s) Frequency (MHz)

YES On-Board Data Processing Required

Description

Data Types: X Analog X Digital 8 Hours/day

Film (Amount) Voice (hours/day) 8

Live TV (hours/day) Other

On-Board Storage (Mb) 1

Data Dump Frequency (Per Orbit) 1

Recording Rate (kb/s) 40 Downlink Frequency (MHz) TBD

THERMAL - Dependent on optical configuration

x Active x Passive

Temperature, deg C	operational min TBD	max TBD	
	non-operational min TBD	max TBD	
Heat Rejection, W	operational min TBD	max TBD	
	non-operational min TBD	max TBD	

EQUIPMENT PHYSICAL CHARACTERISTICS primary mirror composed of seven hexagonal panels, each 3M peak-to-peak

Location: ___ Internal x External ___ Remote

Equipment ID/Function ___ Pressurized x Unpressurized

L,m 4	W,m 4	H,m 15	Stowed
L,m 24	W,m 18	H,m 15	Deployed

Launch Mass, kg 7,500

Consumables Types none

Acceleration Sensitivity, g min TBD max TBD

CREW REQUIREMENTS - TBD

Crew Size 2 Task Assignment set-up; operate; service

Skills (See Table B)

SKILL	.	.	.	.	.	.	.
LEVEL	.	.	.	.	.	.	.
Hours/day	.	.	.	.	.	.	.

EVA x Yes ___ No Reason ___ Hours/EVA 8 max.

SERVICING/MAINTENANCE

SERVICE: Interval, days 30 Consumables, kg 0

Returnables, kg TBD Workhours 1

CONFIGURATION CHANGES: Interval, day ___ Workhours Req. ___

Deliverables, kg ___ Returnables, kg ___

SPECIAL CONSIDERATIONS/See Instructions

APPENDIX B

UPDATE OF MISSION DESCRIPTION SAAX-0020

*** NAME ***

PAYLOAD ELEMENT NAME	LARGE DEPLOYABLE REFLECTOR
LAST UPDATE	100385
COUNTRY OF ORIGEN	USA
CONTACT	DONALD L. AGNEW GOVERNMENT SYSTEMS DIVISION, EASTMAN KODAK COMPANY 901 ELMGROVE ROAD ROCHESTER, NY 14650
PHONE NUMBER	(716) 253-2377
STATUS	PLANNED

*** FLIGHTS ***

FIRST FLIGHT YEAR	1997					
NUMBER OF FLIGHTS	1					
SUBSEQUENT FLIGHT DATES	-9999	-9999	-9999	-9999	-9999	
DURATION OF FLIGHTS (DAYS)	3600	0	0	0	0	0
OPERATIONAL DAYS PER YEAR	365					

*** OBJECTIVE ***

TO CONDUCT INFRARED AND SUBMILLIMETER ASTRONOMICAL INVESTIGATIONS FOR THE SURVEY OF A WIDE VARIETY OF ASTROPHYSICAL PHENOMENA THROUGHOUT THE SPECTRAL REGION.

*** DESCRIPTION ***

LDR WILL BE BROUGHT TO THE SPACE STATION ON SEVERAL SHUTTLE LOADS. IT WILL BE ASSEMBLED AND TESTED AT THE STATION. IT GETS PLACED IN OPERATIONAL ORBIT BY THE OMV AND IS PERIODICALLY SERVICED.

*** TYPE/SCALE ***

TYPE NUMBER	1
IMPORTANCE OF SPACE STATION	9

*** ORBIT ***

APOGEE (KM)	700.0
+TOLERANCE (KM)	100.0
-TOLERANCE (KM)	100.0
PERIGEE (KM)	700.0

+TOLERANCE (KM)	100.0
-TOLERANCE (KM)	100.0
INCLINATION (DEG)	28.50
+TOLERANCE (DEG)	70.00
-TOLERANCE (DEG)	10.00
LOCAL TIME OF EQUATOR CROSSING NODE	NO DATA

*** POINTING/ORIENTATION ***

VIEW DIRECTION	INERTIAL
TRUTH SITES	
POINTING ACCURACY (ARC SEC)	1.00
FIELD OF VIEW (DEG)	0.0
POINTING STABILITY RATE	NO DATA
POINTING STABILITY (ARC/SEC)	0.000

SPECIAL RESTRICTIONS AVOID SUN BY 60 DEGREES, AVOID EARTH BY 45 DEGREES

*** POWER ***

	DC
OPERATING (KW)	5.00
HOURS PER DAY (OPERATING)	24.0
VOLTAGE	-999.9
PEAK (KW)	-99.99
HOURS PER DAY (PEAK)	-99.9
STANDBY POWER (KW)	-9.99

*** DATA/COMMUNICATIONS ***

TRANSMISSION REQUIREMENTS:
REALTIME
OFFLINE
OTHER
TDRSS COMPATIBLE

ENCRYPTION REQUIRED:	NO
UPLINK REQUIRED:	YES

COMMAND RATE (KBPS)	100.00
FREQUENCY	NO DATA
ONBOARD DATA PROCESSING REQUIRED:	YES
DESCRIPTION	
DATA TYPE	DIGITAL
HOURS/DAY	24.0
FILM	NO DATA
VOICE	YES
LIVE TV	YES
OTHER	
ONBOARD STORAGE (MBIT)	2000.00
DATA DUMP FREQUENCY (PER ORBIT)	
NOMINAL	NO DATA
MINIMUM	NO DATA
MAXIMUM	NO DATA
RECORDING RATE (KBPS)	400.00
DOWNLINK RATE	NO DATA
STATION DATA REQUIRED	
ON ORBIT TRANSMISSION RATES	

*** THERMAL ***

ACTIVE:	YES
PASSIVE	YES
TEMPERATURE (DEG C)	
OPERATIONAL MIN	-148.0
OPERATIONAL MAX	-75.0
NON-OPERATIONAL MIN	0.0

NON-OPERATIONAL MAX	20.0

HEAT REJECTION (KW)

OPERATIONAL MIN	5.00
OPERATIONAL MAX	5.00
NON-OPERATIONAL MIN	1.00
NON-OPERATIONAL MAX	1.00

*** EQUIPMENT ***

INTERNAL/PRESSURIZED	YES
EXTERNAL/ATTACHED/PRESSURIZED	YES
EXTERNAL/ATTACHED/UNPRESSURIZED	YES
REMOTE (FREE FLYER)	YES
PLATFORM COMPATIBLE	YES

DIMENSIONS (ALL VALUES IN METERS)

INTERNAL		
	LENGTH	NO DATA
	WIDTH	NO DATA
	HEIGHT	NO DATA
EXTERNAL		
	LENGTH	40.00
	WIDTH	35.00
	HEIGHT	35.00
PACKAGED		
	LENGTH	28.00
	WIDTH	4.00

HEIGHT 4.00

LAUNCH MASS (KG) NOMINAL 57,000.00
MAXIMUM NO DATA

ACCELERATION (G) MINIMUM 0.0000000
MAXIMUM 0.1000000

*** CREW OPERATIONAL TASKS ***

IVA
CREW SIZE NO DATA

TASK ASSIGNMENT:
SKILLS:
SKILL LEVEL:
HOURS/DAY/SKILL: -99.99 -99.99 -99.99 -99.99 -99.99 -99.99 -99.99 -99.99 -99.99 -99.

NOTE: NUMBER OF SKILLS NEED NOT MATCH CREW SIZE
IF CROSS TRAINING ALLOWED

EVA YES

*** SERVICING ***

CONSUMABLES
TYPE: SUPERFLUID HELIUM; LIQUID HELIUM; LIQUID HYDROGEN; LIQUID NITROGEN
WEIGHT (KG) 7,500 KG
RETURN WEIGHT NO DATA
SERVICING EVA YES

SERVICING IVA
SERVICE INTERVAL (DAYS) 730
HOURS PER SERVICING 24.00
TYPICAL TASKS: OHV PREPARATION

*** CONFIGURATION CHANGES ***

DELIVERABLES (KG) 57,000.00

RETURNABLES NO DATA

CONFIGURATION CHANGE EVA
    INTERVAL (DAYS) 2185
    HOURS PER CHANGE 25.00
    TYPICAL TASKS: DEPLOY AND ASSEMBLE TELESCOPE

CONFIGURATION CHANGE IVA
    INTERVAL (DAYS) 2185
    HOURS PER CHANGE 25.00
    TYPICAL TASKS: RMS, ENGAGING DEPLOYMENT MECHANISMS, MONITORING

*** CONTAMINATION SENSITIVITIES ***
EXTREME CONCERN ABOUT CONTAMINATION OF OPTICAL SURFACES

*** SPECIAL CONSIDERATIONS ***

DESIGN OF LDR IS UNDER STUDY
LARGE INTERNAL VOLUME REQUIRED FOR GENERIC INTERNAL STORAGE & OPTICAL
WORK AREA

APPENDIX C

GLOSSARY OF TERMS AND ACRONYMS

ACC	Aft Cargo Carrier or Aft Cargo Compartment
ACCESS	Assembly Concept for Construction of Erectable Space Structures
ADR	Adiabatic Demagnetization Refrigerator
ARC	Ames Research Center
ASE	Airborne (Aerospace) Support Equipment
CER	Cost Estimate Relationships
CDR	Critical Design Review
CMG	Control Moment Gyro
CTE	Coefficient of Thermal Expansion
DARPA	Defense Advance Research Projects Agency
DDT&E	Design, Develop, Test and Evaluate
DoD	Department of Defense
EASE	Experimental Assembly of Structures in Extravehicular Activity
ECLSS	Environmental Control/Life Support Systems
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
FIR	Far Infrared
FOV	Field of View
FSC	Fairchild Space Company
GFE	Government Furnished Equipment
GN&C	Guidance, Navigation and Control
HM	Habitation Module
HPA	Holding and Positioning Aid or Handling and Positioning Adapter
IDR	Interim Design Review
I/F	Interface
IR	Infrared
IR&D	Independent Research and Development
IVA	Intravehicular Activity
JPL	Jet Propulsion Laboratory
KBPS	Kilobytes Per Second
LaRC	Langley Research Center
LHe	Liquid Helium
LH_2	Liquid Hydrogen
LM	Logistics Module
LN_2	Liquid Nitrogen
M	Meter
MDAC	McDonnell Douglas Astronautics Company
MMU	Manned Maneuvering Unit
MPESS	Mission Peculiar Experiment Support Structure
MRMS	Mobile Remote Manipulator System
OPS	Operations
OAST	Office of Aeronautics and Space Technology
OMS	Orbital Maneuvering System
OMU	Orbital Maneuvering Unit
OMV	Orbital Maneuvering Vehicle
ORU	Orbit Replaceable Unit
OSSA	Office of Space Science and Applications - Code E
OSS	Office of Space Station - Code S
PAM	Payload Assist Module
PACS	Pointing and Control System

PDR	Preliminary Design Review
PI	Principal Investigator
PIDA	Payload Insertion Deployment Aid
PM	Primary Mirror
PSIA	Pounds Per Square Inch Absolute
RMS	Remote Manipulating System
RQM	Requirement
SAA	Science and Applications
SAAX	Science and Applications Missions
SC or S/C	Spacecraft
SCG	Science Coordination Group
SE&I	Systems Engineering and Evaluation
SDV	Shuttle Derived Vehicle
SI or S/I	Science Instrument
SIS	Superconductor-Insulator-Superconductor
SIRTF	Space Infrared Telescope Facility
SM	Secondary Mirror
SMM	Submillimeter
SOW	Statement of Work
SS	Space Station
STEP	Space Technology Experiments Platform
STS	Space Transportation System
T&C	Telemetry and Command
TDMX	Technology Development Missions
TDP	Technology Development Program
TDRS	Tracking and Data Relay Satellite
TSS	Tethered Satellite System
TT&C	Telemetry, Tracking and Command

APPENDIX D

LEGEND OF SYMBOLS, CONSTANTS, AND NUMERICAL VALUES

$\widehat{\text{sec}},\widehat{\text{min}}$	ARCSECONDS, ARCMINUTES

APPENDIX E

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR 177414		

4. Title and Subtitle
LARGE DEPLOYABLE REFLECTOR (LDR) SYSTEMS CONCEPT AND TECHNOLOGY DEFINITION STUDY - ANALYSIS OF SPACE STATION REQUIREMENTS FOR LDR

5. Report Date
April 1989

6. Performing Organization Code

7. Author(s)
D.L.AGNEW, V.F.VINKEY, F.C.RUNGE *

8. Performing Organization Report No.

10. Work Unit No.
506-62-21

9. Performing Organization Name and Address
EASTMAN KODAK COMPANY
GOVERNMENT SYSTEMS DIVISION
RESEARCH AND ENGINEERING; ROCHESTER,N.Y. 14650

11. Contract or Grant No.
NAS2-11861

13. Type of Report and Period Covered
Contractor Report

12. Sponsoring Agency Name and Address
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546-0001

14. Sponsoring Agency Code

15. Supplementary Notes
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16. Abstract
A study was conducted to determine how the Large Deployable Reflector might benefit from the use of Space Station for Assembly, checkout, deployment, servicing, refurbishment, and technology development. Requirements that must be met by Space Station to supply benefits for a selected scenario are summarized. Quantitative and qualitative data are supplied. Space Station requirements for LDR which may be utilized by other missions are identified. A technology development mission for LDR is outlined and requirements summarized. A preliminary experiment plan is included. Space Station Data Base SAA 0020 and TDM 2411 are updated.

* McDonnell Douglas Astronautics Company
Huntington Beach, California

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Large Deployable Reflector (LDR), Observatory, Spaceborne Telescope, Infrared Astronomy, Submillimeter Astronomy	Unclassified - Unlimited Subject category: 12

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	115	A06

*For sale by the National Technical Information Service, Springfield, Virginia 22161